



Transportation economics and environmental issues that influence product strategy

Interim report

Prepared for **Tata Engineering**

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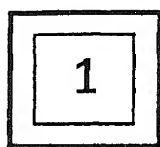
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Introduction

Background

Transport is a sector which clearly needs to be addressed in response to a series of major public policy objectives such as energy security, human health, safety, local environment, climate change and last but not least, the economic affordability. For the time being, energy policy goals must be content with taking a back seat relative to transport and environment policies and institutions which take precedence over energy in this field.

Automobile and fuel technologies: solutions for the environment

Although the environment and health burden associated with motor vehicle use is pervasive and persistent, and the certain, rapid growth of the world fleet presents a tremendous challenge, there is cause for optimism. Both industrialized and developing nations have taken major steps in recent years to control vehicle emissions and improve efficiency. Strong programmes in several countries have produced impressive emissions reductions and efficiency improvements over the last thirty years, indicating a similar potential for improvement in countries with younger programmes. Emerging technologies, in combination with intelligent policies, offer hope for dramatic emissions reductions into the future. Automobile manufacturers are bringing forward new technologies such as catalysed particulate traps, continuously variable transmissions, lightweight materials, hybrid-electric drive trains, advanced gaseous-fuel engines, and fuel cell vehicles. Battery-electric vehicles and small size cars are finding niche markets. Refineries are beginning to produce reformulated, very low sulphur fuels that enable advanced emissions technologies.

Technologies to reduce emissions from spark-ignition (i.e., gasoline-powered) engines were first introduced in the United States and Japan in the late 1960s. Europe followed with similar regulations a decade later. Standards for exhaust emissions, and for evaporative emissions of volatile organic compounds (VOCs) from vehicle fuel systems, have become progressively more stringent and are scheduled to continue that trend. Emissions from new vehicles

in the most strictly controlled regions are 90% to 98% lower than they were prior to control. Other parts of the world are following this step-by-step regulatory approach, though with some lag.

The emissions from vehicles powered by compression-ignition (i.e., diesel) engines (including trucks, off-road construction vehicles, and railroad locomotives) are less strictly regulated than emissions from gasoline engine vehicles, in part because exhaust treatment emission control devices – catalysts for NO_x, traps for particulates – are not sufficiently developed to enable their widespread use. Both technologies are progressing, and plans are in place to reduce NO_x and particulate emissions significantly from current levels.

The adoption of more effective abatement technologies (generally in response to stricter government-imposed emissions standards) will lead to significant reductions in per-vehicle emissions rates. This will not, however, automatically translate into equivalent reductions in total vehicle-related emissions due to rapid urbanization, motorization, the lag in adopting more recent vehicle pollution control devices (in part due to the need to upgrade fuel quality and fuel distribution systems), and slow turnover of vehicle fleets, particularly in the developing world. As a result of expected growth in population and gross domestic product (GDP), the next few decades will see strong growth in the worldwide vehicle fleet, especially in the rapidly industrializing countries of Asia. This growth is overtaking what are otherwise very successful efforts in many countries to reduce vehicle emissions.

Use of non-renewable, carbon based energy

Transportation not only requires a great deal of petroleum, it needs very little energy other than petroleum. Fuels derived from petroleum now account for more than 96% of all the energy used in transportation. There has been no sign of any decrease in that percentage (IEA, 2000). Other sources of transportation energy – coal, natural gas, alcohols, electric power – have been significant in particular places or times but all have been minor fractions of the total.

According to the International Energy Agency (IEA), it is expected that in a business-as-usual scenario the consumption levels of fuels in the transport sector would at least double the level of today in 25 to 30 years (IEA 2000; EIA/US DOE 2001). The major question is for how long will producers of petroleum, a huge but ultimately limited resource, be able to satisfy transportation's ever-increasing demand for oil? And at what price? Linked to availability of supply is the fact that 65% of the world's known reserves of conventional petroleum are located in the Middle East (BP, 2000), and there is

concern about the rest of the world being so dependent on what has been a politically volatile region. Greater emphasis has to be laid on use of alternative fuels in the transport sector.

The more pressing issue is not the availability of fuel but carbon dioxide (CO₂) emissions resulting from the production/manufacture and use of fuel, whether the fuel is derived from conventional petroleum, heavy oil, or natural gas. Switching from petroleum-like fuels to other fuels that emit less CO₂ during their manufacture and use could mitigate CO₂ emissions from the use of transportation fuels. That is the principal driving force behind the current interest in fuels such as ethanol or methanol that are derived from biomass, and in fuels such as hydrogen or electric power that are derived from sources of primary energy that do not emit CO₂. Presently, there are many economic, technical, and other barriers to the commercialisation of these alternative fuels, but further work can reduce many of those barriers.

Key questions in the Indian context

In India, as a result of air quality concerns, all types of vehicles have been subjected to increasingly stringent emission standards. For this it is imperative that both fuel specifications and engine technology go hand in hand. Advances and improvements in technology and fuel quality now provide a choice of fuels from which one that reduces particulate matter emissions the main pollutant of concern in most Indian cities can be related. These however translate into high costs for vehicle manufactured and refineries. In a large but poor country such as India it is essential to evaluate the cost of different options especially if they yield comparable results in order to determine the most cost-effective solution. In view of the growing demand for clean fuels in the transport sector, it is important to determine the cost of supplying clean fuels to dispensing stations in major cities.

With the technological advancements travel speeds have increased, as a result the importance of proximity has somewhat declined. Today, two overarching phenomena are shaping the pattern of human settlements. The first of these is urbanization – the tendency for populations to concentrate in cities. The second is decentralization – the tendency of these same urban areas to expand outwards into satellite towns and suburbs, generally at rates faster than overall population growth.

Mobility systems affect urban growth in an important way because they make areas of a city more or less accessible, altering the land values and an area's attractiveness for various uses. Transportation investments often open up

new areas for development. For instance a highway on an urban fringe that facilitates suburbanization around the existing urban core.

Given the current situation in India, many pertinent questions arise that influence product development strategy in the transport sector. Some of these include -

1. What is the trend in urbanization?
2. What are the impact on air quality status in major cities and the major sources of pollution?
3. What are the health impacts and costs due to air pollution?
4. How is the trend in prescribing emission norms emerging and future action likely to be?
5. How and to what extent, motorized transport contributes to pollution?
6. Which are the emerging fuels and technologies?
7. What are the implications on fuel infrastructure development and fuel pricing?
8. What is the relationship between growth rates of population, GDP and growth in motor vehicles?

Scope and objectives

The Tata Energy Research Institute (TERI), New Delhi was awarded a six-month study (July – December 2002) by the Tata Engineering and Locomotive Company Limited (TELCO), Mumbai to develop a policy document intended to help TELCO to assess and develop its research and product development strategy.

The primary objective of this study is to develop an objective and well researched policy document that provides a comprehensive review of current practices and emerging trends in controlling vehicle emissions in the urban transport sector with particular reference to Indian urban infrastructure and population conditions.

More specifically, the objectives are to -

- analyze the health effects of air pollution and costs,
- analyze the atmospheric quality in major Indian cities,
- review the current and pending environmental regulation in India and abroad,
- provide an overview of the development in fuel quality and alternative fuels,
- provide an overview on the development of power packs as alternatives,

- provide an overview on the development of emission control technologies,
- carry out an assessment of fuel infrastructure and pricing issue, and
- estimate vehicle projections.

Coverage of this interim report

This interim report at the end of 3 months provides an overview of what the TERI project team has studied so far with some broad conclusions.

Air pollution in general is defined as an imbalance in air quality to such an extent to cause severe impairment and to result in serious health impacts. Pollutants have both natural and manmade sources. Gases such as carbon monoxide (CO), sulphur dioxide (SO₂), hydrogen sulphide (H₂S) are continuously released into the atmosphere through natural activities like volcanoes, vegetation decay and forest fires. Besides these gaseous releases, tiny particles of solids or liquids are distributed throughout the air due to various natural disturbances. Anthropogenic emissions of air pollutants are generally associated with the level of economic activity. Rising population has resulted in increased urbanisation and industrialisation, which in turn has resulted in an increase in these emissions and deterioration of air quality. The quality of air is essential as it poses deleterious effects on human health. All pollutants released both natural and manmade exists mostly below 2000 feet from the ground level (De, 1994).

Each day, an adult human inhales about 15 cubic meters of air (<http://www.epa.nsw.gov.au/leadsafe/>). Polluted air reduces the lung capacity and has varied health impacts. Air pollution is said to have greater effect on children, the elderly, and people with lung problems such as asthma, allergies, and emphysema.

Air pollution, sources and health impacts

Air pollutants are classified as primary or secondary, based on their characteristics at the time of emissions and physical/chemical changes, they undergo while in the atmosphere. Primary air pollutants are those which are emitted directly from identifiable sources and tend to be very simple in chemical structure like carbon monoxide, sulphur dioxide, nitrogen dioxide from combustion sources; hydrogen sulphide, ammonia, hydrogen fluoride, from industrial processes and gases such as paraffins, olefins and aromatics which evaporate easily. The pollutants which are produced in air by interaction among two or more primary pollutants, or by reaction with normal atmospheric constituents, with or without photo activation are known as secondary pollutants for e.g. Peroxy Acetyl Nitrate (PAN), Ozone etc.

Regulated pollutants and their health effects

The six major air pollutants which are regulated, also known as criteria/critical/principal pollutants, on which much of the work on air pollution on the last few decades have centred on are carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), sulphur dioxide (SO₂), lead (Pb) and ozone (O₃). These pollutants originate largely from stationary sources (industries, power plants, and municipal incinerators); small stationary sources (households and small commercial boilers) and mobile sources (traffic). Many of the sources are closely related to the production and consumption of energy, especially fossil fuels. Besides industries, domestic use of biomass and coal also contribute to emissions. Next to industrial sources, some of the important pollutants like CO, NO_x, SO₂ and particulates (of different sizes) are emitted from the transportation sector. Annex 2.1 provides the possible sources of each of these criteria pollutants, their causes and possible health effects.

In a review paper on particulate matter and health with particular focus on developing countries by the International Institute for Applied Systems Analysis (IIASA), also states that motor traffic is the most important source of PM in cities with high motor vehicle density (Panyacosit,2000). The majority of cars in some developing countries are diesel powered, which generate on the order of ten times more respirable particles than gasoline engines per kilometer driven. A study in Eastern Germany in 1991 and 1992 revealed that ultra fine particles accounted for 73% of the particles per cm³ of air even though their total contribution to the mass concentration of all fine particles was approximately 1% (Panyacosit,2000). The number concentration of particles is dominated by the ultrafine particles whereas the mass concentration of the particles is dominated more so by the slightly larger particles of diameter 0.1-0.5µm. Since most of the data in developing countries in terms of particulates are monitored as total suspended particulate (TSP) and very marginally as PM₁₀, studies have been there to calculate the ratios of PM₁₀/TSP. The range of this ratio is from 0.4-0.8 (Panyacosit,2000). A study has also pointed out that PM_{2.5} dominates both the PM₁₀ mass and number concentrations and is a cause of day-day variability of PM₁₀ (Panyacosit,2000). The conclusion of the study was that it is reasonable to use PM₁₀ as a proxy for exposure to PM_{2.5} (Panyacosit, 2000).

Carbon monoxide

CO reduces the oxygen carrying capacity of the blood. It binds with haemoglobin to form carboxy haemoglobin (COHb). The relationship between ambient CO concentrations in air and COHb levels in blood depends mainly on the duration

of exposure and the pulse rate of the exposed person (i.e. the intensity of physical effort). CO uptake impairs perception and thinking, slows reflexes, and may cause drowsiness, angina, unconsciousness, or death (World Bank, 1997).

Exposure of CO to pregnant women has been linked to low birth weight and retarded postnatal development. Table 2.1 presents the effects of CO under various concentration and its observed health effects in human beings.

Table 2.1 Health effects of CO under various concentrations

Concentration	Exposure time	Observed effects	Other effects
40ppm	>2 hours	Adversely effects a persons ability to make judgements	Developmental toxicity: Exposure of pregnant women to CO has been linked to low birth weight, cardio megalay, delay in behavioural development, disruption in cognitive functions and sometimes even Sudden Infant Death Syndrome(SIDS)
100ppm	3.5 hours	Impairment of visual perception, of manual dextenty, of learning, and impairment of performance of certain intellectual tasks	
75ppm	2-4 hours	Headaches	Cerebro-vascular and behavioral effect: Due to increase in cerebral blood flow as a result of hypoxia it may lead to head injury, atherosclerosis, hypertension.
873ppm	2-4 hours	Strong headache, nausea, fatigue, dizziness, increase in pulse rate leading to convulsions and coma	
1598ppm	1-2 hours	Death	

Source. CPCB 2001(a,b); Stern A C (ed) 1977, World Bank 1977; CPCB 2002

Nitrogen dioxide

It is an irritating gas that is absorbed into the mucous membrane of the respiratory tract. Exposure to NO₂ increases susceptibility to respiratory infection, increase airway resistance in asthmatics and decreases pulmonary function. Table 2.2 presents the effects of NO₂ under various concentration and its observed health effects in human beings.

Table 2.2 Health effects of NO₂ under various concentrations

Concentration	Exposure time	Observed effect	Other effect
2.5ppm	<2 hours	Pronounced decrease in pulmonary function	Exposure in large doses can result in dysfunction of host defences by causing structural alteration in ciliated cells of mucociliary escalator, in alveolar macrophages, decrease in production of sulphur dioxide anion radical (bactencidal), decrease in phagocytosis etc. The adverse effects are seen after the exposure has ceased
5.0ppm	15 minutes	Decreased diffusion capacity	
50ppm	1 minute	Respiratory tract imtation	
0.1ppm	1-3 years (continuous exposure)	Increase incidence of bronchitis, emphysema, oedema	
0.4-2.7ppm	180 days (long-term, intermittent exposure)	Increase in blood lipids, lipoproteins and cholesterol	

Source. CPCB 2001(a,b); Stern A C (ed) 1977; World Bank 1977; CPCB 2002

Sulphur dioxide

SO₂ is associated with reduced lung function and increased risks of mortality and morbidity. Adverse health effects of SO₂ include coughing, phlegm, chest discomfort, and bronchitis. SO₂ exacerbates the effects of PM and vice versa. Some of the SO₂ emissions are transformed in the atmosphere into sulphate aerosols, which are associated with mortality and morbidity. It has been estimated that a 10 µg /m³ change in ambient concentration of SO₂ would cause 10-26 cough incidents among 100,000 children and 5 to 15 chest discomfort incidents among 100 adults (World Bank ,1997).

Although ambient concentrations of SO₂ has declined in many cities in western Europe and North America, they remain higher- often by a factor 5 to 10 in a number of cities in Eastern Europe, Asia and South America , where residential or industrial coal use is still prevalent or diesel traffic is heavy (WRI, 1998). In India, the SO₂ concentration is well within the permissible limits. Table 2.3 presents the effects of SO₂ under various concentration and its observed health effects in human beings.

Table 2.3 Health effects of SO₂ under various concentrations

Concentration	Exposure time	Observed effects	Other effects
0.0035-0.1ppm	>3 years	Excessive acute respiratory disease in communities heavily polluted with SO ₂ and sulphates	Chronic ambient exposure may result in increased risk of morbidity and/or mortality and also of chronic bronchitis. The adverse effects of SO ₂ is aggravated when in combination to particulates and more pronounced in persons suffering from asthma
0.52ppm	15 minutes	Increased eye sensitivity to light during dark adaptation	
1.6 ppm	-	Lowest concentration resulting in bronchoconstriction	
2.0- 5.00ppm	3-10 minutes	Increased airway resistance	

Source. CPCB 2001(a,b); Stern A C (ed) 1977; World Bank 1977, CPCB 2002

Lead

Lead affects virtually every system in the body. It can cause high blood pressure and can also affect the renal, nervous and reproductive systems. Chronic exposures with elevated blood lead levels are associated with hypertension, headache, confusion, irritability, and insomnia. Further higher levels cause drowsiness, loss of muscular coordination and susceptibility to infection and anaemia. Lead is more easily absorbed in children than adults and results in lower intelligence quotients, reading and spelling underachievement, impairment of visual motor function, poor perception integration, disruptive behaviour and impaired reaction time. It has been estimated that a 1µg/m³ increase in ambient lead levels would cause a 0.975 IQ point decrement per child, 20-65 premature deaths and 18-50 non-fatal heart attacks among

100,000 40-59 year old males and 45-98 hypertension cases among 1000 20-70 year old males (World Bank, 1997).

Ozone

Ozone pollution has become widespread in cities of Europe, North America, and Japan as auto and industrial emissions have increased. Many cities in the developing countries also suffer from high ozone levels, though few monitoring data exists. In India, the high concentrations of precursors such as NO₂ and hydrocarbons and climatic conditions suggest that ozone levels may be high in sub-urban areas, but the data is limited. This suggests that there is need for ozone monitoring. A powerful oxidant, ozone can react with any biological tissue. Breathing ozone concentrations of 0.012 ppm—levels typical in many cities—can irritate the respiratory tract, impair lung function, causing coughing, shortness of breath, and chest pain. Evidence also suggests ozone exposure lowers the body's defences, increasing susceptibility to infections and can cause premature ageing. In recent analysis of ozone health impacts in 13 cities where ozone levels exceeded U.S air quality standards, the American Lung Association estimated that high ozone levels were responsible for approximately 10,000-15,000 extra hospital admissions and 30,000-50,000 additional emergency room visits during the year 1993-94 (WRI, 1998). Table 2.4 presents the varied effects of O₃ under various concentration and its observed health effects in human beings.

Table 2.4 Health effects of O₃ under various concentrations

Concentration	Exposure	Effects	Other effects
1ppm	2 hours	Reduction in vital capacity and maximal breathing capacity	Short term adverse effect include eye, nose and throat irritation, coughing, throacic pain, increased mucous production, chest tightness, lassitude, malaise and nausea.
0.5ppm	3 hours per day for 6 weeks	Progressive decrease in 1 second forced expiratory volume	Systemic effects: Sphernng of erythrocytes, chromosome breakage in lymphocytes, retardation of deoxygenation of haemoglobin, premature aging.

Source. CPCB 2001(a,b); Stern A C (ed) 1977, World Bank 1977; CPCB 2002

Particulates

The World Bank has estimated that exposure to particulate levels exceeding the WHO health standard accounts for roughly 2 to 5 percent of all deaths in urban

areas. In the developing world it is said to cause some 50 million cases per year of chronic coughing in children younger than 14 years of age (WRI, 2002).

PM is a complicated blend of chemicals that is dependent upon the primary source from which it originates but also meteorological factors, which could influence to what extent certain compounds, will undergo secondary chemical transformations. The topological features as well as certain seasonal features can either exacerbate or lessen the problems related to the severity of air pollution (Panyacosit, 2000). Thermal inversion reduces the dilution and dispersion capability of the atmosphere and trap air pollutants (including PM). Apart from the particulate size range, characteristic human and environmental component dictates the type and frequency of human health effects observed. The health effects depend on the exposed individual's physical characteristics, breathing mode, rate and volume as well. The environmental component is influenced by local conditions such as weather, seasons, topography, sources of particles, the concentration being emitted and microenvironments. All these components differ significantly among regions and populations. Concentrations also depend on whether PM has a long or short distance transport and trans-boundary air pollution problem, which could have serious repercussions for the area surrounding the polluted area.

PM in ambient air has been associated with increased mortality, morbidity, and reduced lung function. It causes change in respiratory health status and depicts several symptoms in the upper respiratory tract such as stuffy or runny nose, sinusitis, sore throat, wet cough burning or red eyes. The lower respiratory symptoms include wheezing, dry cough, shortness of breath (Dyspnoea), chest discomfort and pain. During major pollution events, such as those involving a $200\mu\text{g}/\text{m}^3$ increase in particulate levels, an expert panel at WHO estimated that daily mortality rates could increase as much as 20% (WRI, 1998). USEPA guidelines for PM_{10} give $50\mu\text{g}/\text{m}^3$ for annual average and $150\mu\text{g}/\text{m}^3$ for daily average. As per 1999 WHO guidelines, no guideline value for short term average concentration of PM has been recommended. Since then however new evidence has come into light that those published guidelines are not low enough to safeguard against adverse health effects. There may be no concentration that is low enough to safeguard against adverse health effects as no threshold has ever been established through animal studies or through epidemiological studies. Morbidity and mortality endpoints have been observed at levels even below the stated air quality guidelines put forth by USEPA (Panyacosit, 2000)

Occupational exposure to particulate matter containing specific chemical dust may lead to silicosis, asbestosis, pneumoconiosis etc. PM containing

arsenates, chromates, PAHs, nickel containing dust act on lung tissue can cause carcinoma. Small particulates like $PM_{2.5}$ are more dangerous in comparison to PM_{10} because they can be inhaled deeply into the lungs, settling in areas where the body's natural clearance mechanism cannot remove them. The constituents in these small particulates also tend to be more chemically active and acidic therefore causing much damage. There are however limited number of epidemiological studies that have specifically addressed $PM_{2.5}$. These appear to provide limited evidence of an association between $PM_{2.5}$ levels and acute and chronic mortality available at present (CONCAWE 1999a).

Un-regulated pollutants and their health effects

Apart from the regulated pollutants, there are various unregulated pollutants viz. Volatile Organic Compounds (VOC) like aldehydes, ketones, organic acids, alcohols, furans etc; Poly Aromatic Hydrocarbons (PAH's) like benzo (a) pyrene, benzo (b) flouranthene, benzo (a) antheracene, cyclopenteno (c-d) pyrene, and trace metals like lead; which have there origin from the transportation sector and are toxic in nature. Annex 2.2 provides the possible sources of some of the un-regulated pollutants, their causes and possible health effects.

Hydrocarbons

Though Hydrocarbons are defined chemically as compounds consisting of carbon and hydrogen but in air quality studies it is extended to include VOCs like alcohols, aldehydes and other non-methane organic compounds. Most of the hydrocarbons are not directly harmful to health at concentrations found in the ambient air but when they undergo chemical reactions in the troposphere they form ozone and NO_2 which are health and environmental hazards. Methane is removed from the group of hydrocarbons due to its lack of reactivity as well as toxicity effect, so we have the remaining hydrocarbons (nonmethane hydrocarbons) which are reactive in forming secondary air pollutants and thus are the focus of air quality studies (World Bank, 1997).

Poly aromatic hydrocarbons

PAHs is a common term, which includes a number of hydrocarbons that are aromatic in nature having ringed structures. PAHs in air have their origin from the combustion of fuels and hence the transportation sector contributes significantly to their levels in ambient air. Generally they are characterised by the presence of two to six benzene rings and are contained in small amounts in the exhaust gases of diesel and gasoline engines. The lightest among them (two

or three rings) are present in gaseous emissions, while the heavier ones (four or more rings) are found in the soluble particles or in the agglomerations of soot. The simultaneous presence of PAHs and oxides of nitrogen in combustion products favour the formation of nitro-PAHs, which are potent mutagens. Table 2.5 lists out some of the major PAH emitted from vehicles using gasoline and diesel fuels.

Table 2.5 Major PAHs present in engine exhaust (gasoline and diesel)

Products	Number of nngs	Relative Proportion within PAH group			Likely carcinogenic characteristics*	
		Minimal	Significant	None (3)	Unproven 2 (2B)	Probable (2A)
Naphthalene	2		•	•		
Acenaphthylene	3		•	•		
Fluorene	3		•	•		
Phenanthrene	3		•	•		
Anthracene	3	•		•		
Fluoranthene	4		•	•		
Pyrene	4	•		•		
Chrysene	4	•				
Benzo [a] anthracene	4		•			•
Benzo [b] fluoranthene	5				•	
Benzo [k] fluoranthene	5		•		•	
Benzo [e] pyrene	5	•		•		
Benzo [a] pyrene	5		•			•
Indenopyrene	5	•			•	
Dibenzo [a, h] anthracene	5	•				•
Benzo [g, h, i] perylene	6	•		•		
Coronene	7	•		•		

*The notations, 3, 2B and 2A refer to the international classification system of the International Agency for Research on Cancer (IARC).

Source: Guibet, 1999

Carbon dioxide

Though not a pollutant by itself, it is the most significant greenhouse gas contributing to global warming. With respect to total CO₂ emissions, the world energy balance shows that the transportation sector (~29%) is the largest producer of CO₂ after the industrial sector (~34%) and within the transportation sector, road transportation holds an overwhelming proportion of 76% (Guibet, 1999). In India, it was estimated that CO₂ emissions from the use of petroleum products in the transportation sector alone for the period 1980/81 to 1995/96 increased at a rate of 7.5% per year. Over this 15 year period, the concentration has increased from 8.8 to 26.2 TgC (TERI, 1996).

Chlorofluorocarbons (CFCs)

The source of CFC emissions from motor vehicles is the Freon gases used in air conditioners. The contribution of motor vehicles to global CFC emissions is estimated at about 28% (World Bank, 1997). Unlike other pollutants, CFCs are

unaffected by natural cleansing mechanisms such as rain. CFCs destroy ozone molecules in the stratospheric layer, which implies more exposure to ultraviolet radiation with a wavelength range of 295nm to 300nm (UV-B) which is biologically the most damaging (World Bank, 1997).

Air toxics

Air toxics are complex chemicals that have been identified as being toxic to humans. Hundreds of air toxic compounds have been identified to have sources linked to the transportation sector. The EPA currently regulates 188 toxics. But we summarise here the major toxic air pollutants namely benzene, formaldehyde, 1,3 butadiene, acetaldehyde and diesel particulate matter. These have been under study and discussion more often. Standards, except in the US, have not been set and there are only limited studies on the cause and effect of air toxics. Some of most prominent ones are being debated and would soon be included under monitoring and subsequent inclusion in country's standards.

People exposed to toxic air pollutants at sufficient concentrations and durations may have an increased chance of getting cancer or experiencing other serious health effects (Table 2.6). These health effects can include damage to the immune system, as well as neurological, reproductive (e.g., reduced fertility), developmental, and respiratory problems. In addition to exposure from breathing air toxics, risks are also associated with the deposition of toxic pollutants onto soils or surface waters, where they are taken up by plants and ingested by animals and eventually magnified up through the food chain. Like humans, animals may experience health problems if exposed to sufficient quantities of air toxics over time. Most air toxics originate from human-made sources, including mobile sources (e.g., cars, trucks, buses) and stationary sources (e.g., factories, refineries, power plants), as well as indoor sources (e.g., building materials and activities such as cleaning).

Benzene

Acute inhalation and oral exposures of human to high concentration of benzene have resulted in the central nervous system depression and death. Clinical signs of toxicity after acute oral exposure include staggering gait, vomiting, shallow and rapid pulse, somnolence, loss of consciousness, delirium, pneumonitis, profound CNS depression and collapse (Kush, 2001). The most important source for a person daily exposure to benzene is active tobacco smoking. Outdoor concentrations of benzene, due mainly to motor vehicles, account for roughly

one-quarter of the total exposure. Carcinogenic effects include leukemia. The risk of lifetime exposure to 1 µg/m³ of benzene is estimated to range from 0.08-10 excess leukemia deaths per million. The USEPA has classified benzene as a Group A¹ human carcinogen.

1,3 Butadiene

Studies in humans exposed to 1,3 Butadiene suggests that this chemical may cause cancer. EPA has classified *1,3 Butadiene* as a Group B2² probable human carcinogen. Exposure to high levels of (on the order of 100-1000ppm) of this chemical for short periods of time can cause irritation of the eyes, nose and throat. Exposure to further high levels can cause effects on the brain leading to respiratory paralysis and even death (Kush, 2001).

Formaldehyde

Epidemiological studies in occupationally exposed workers suggest that long term inhalation of formaldehyde may be associated with tumors of the nasopharyngeal cavity, nasal cavity, and sinus. EPA has classified formaldehyde as Group B1³ probable human carcinogen. Non cancer adverse health effects associated with exposure to formaldehyde in humans and experimental animals include irritation of the eyes, nose, throat, and lower airway at low levels (0.05-10ppm). Studies in humans and experimental animals indicate that formaldehyde may be a reproductive or developmental toxicant. Adverse effects on the liver and kidney have also been noted in experimental animals exposed to higher levels of formaldehyde.

Acetaldehyde

There is sufficient evidence that acetaldehyde produce cytogenetic damage in cultured mammalian cells. Thus, the available evidence indicates that acetaldehyde is mutagenic and may pose a risk for somatic cells. The USEPA has classified acetaldehyde as a group B2 probable human carcinogen. Animal studies show that primary acute effect exposure to Acetaldehyde vapour is irritation of the eyes, skin and respiratory tract. At high concentrations, irritation and ciliastatic effects can occur, which would facilitate the uptake of

¹ Group A: Human Carcinogen. Requires *sufficient evidence* from human epidemiological studies to support a casual relationship between exposure and the agent.

² Group B: Probable Human Carcinogen. B2 - animal studies are sufficient and in humans the evidence is *inadequate*, no data exists, or no *evidence* is found

³ Group B: Probable Human Carcinogen. B1 - human evidence is *limited* no matter what is found in the animal studies

other contaminants. Respiratory paralysis and death have occurred in extremely high concentrations.

Diesel particles

Diesel particles are known human carcinogen. The physical and chemical characteristics of diesel exhaust have been described recently by Sawyer and Johnson (1995) and Nauss and colleagues (1995). Diesel particulate matter have mass median diameter of 0.05-1.0 μ m, a size rendering them easily respirable and capable of depositing in the airways and alveoli. The carbon core of diesel particulate matter has been linked to its carcinogenic effect in humans and the presence of various PAHs adsorbed on it also render DPM mutagenic. Non-cancer adverse health effects include respiratory tract irritation and diminished resistance to infection. Increased cough and phlegm and slight impairments in lung function has been well documented (Kush, 2001).

Environmental legislations relating to air pollution

Protection of the environment and sustainable use of natural resources, received due attention in the planning process in the early seventies in the country. The committee on human environment was set up in 1970, by the Government of India, to prepare a country report for the Stockholm Conference on Human Environment in June 1972. This conference provided the necessary legislative impetus in India for environmental protection. At this conference, a large number of countries including India committed themselves to protect the environment in all its aspects. After this conference, there were a number of environmental laws introduced in the country among which was the Air (Prevention and Control of Pollution) Act, 1981.

The Air Act provides a framework for the prevention, control and abatement of air pollution and mandates the level of criteria pollutants to below certain levels so as to mitigate the harmful effects of these pollutants on humans. The Central Pollution Control Board (CPCB) and the state boards are the statutory authorities entrusted with the responsibility of implementing the Air Pollution Control Act in the country. The CPCB also has the powers to frame strategies for pollution control for e.g. the **Minimum National Standards (MINAS)** were developed for highly polluting industries.

An air quality standard is a description of a level of air quality, adopted by a regulatory authority as enforceable. Air quality standards are in general defined in terms of one or more concentrations and averaging times. The primary aim of ambient standards is to provide a basis for protecting public health from the

adverse effect of air pollution and to eliminate, or reduce to a minimum, the air pollutants that are hazardous to human health and well being. The ambient air quality standards have both short term, i.e. 24 hourly, and long term, i.e. annual standards set for pollutants such as NO₂, SO₂, RSPM, CO, lead and ozone. The standards have been laid down for industrial, residential and sensitive areas with respect to different pollutants.

The WHO guidelines

Recognising the risks posed by air pollution to humans, the World Health Organisation (WHO), evaluated the health effects of various pollutants and derived the guideline values in 1958. In 1987, the WHO Regional Office in Europe published the Air Quality Guidelines for Europe alone. Since 1993, these guidelines have been revised and updated. Then later, a expert task force meeting was convened in December 1997 in Geneva, Switzerland, where the Guidelines for Air Quality was extended to provide global coverage and applicability (WHO 1999). The guidelines provide a basis for protecting public health from the adverse effects of environmental pollutants and for eliminating, or reducing to a minimum, contaminants that are known for likely hazards to human health and well being at a global level.

The WHO guideline values are levels of air pollution below which lifetime exposure, exposure for a given averaging time, does not constitute a significant health risk. If these limits are exceeded in the short term it does not mean that adverse effects automatically occur; however the risk of such effects increases. Although the Guidelines for Air Quality values are health-or environment-based levels, they are not standards per se. The guideline values actually provide background information and guidance to governments of various countries for making risk management decisions, particularly in setting standards and to carry out local air quality control measures.

Air quality standards in India

The amount of air pollutants released demand that certain level of pollutants be permitted in the atmosphere below which the detrimental effects do not occur. These permissible levels are recognized as air quality standards. The National level standards are a derivation of WHO guidelines. Thus, air quality guidelines help in the setting up of air quality standards by respective governments of different countries taking into consideration a number of parameters like prevailing exposure levels, the natural background contamination,

environmental conditions such as temperature, humidity, altitude and socio economic factors etc (WHO 1999).

In India, the National Ambient Air Quality Standards (NAAQS) were first adopted under the Air Act 1981 and since have been revised by the Central Pollution Control Board in 1994. Currently standards exist for criteria pollutants namely; SO₂, NO₂, CO, SPM and lead for different areas like industrial, residential, rural, mixed use and sensitive areas. Though O₃ is a criteria pollutant, no standard exists as of now and the levels are measured or benchmarked with respect to the available WHO guidelines and U.S. Environmental Protection Agency (USEPA) standards (see Annex 2.3).

Similarly, a number of other pollutants though they have harmful impacts on human health like VOCs, PAHs have not been so far included under the ambient standards of the country. Pollutants such as Benzene, Xylene and Toluene commonly addressed together as BTX are important parameters that indicate the air quality and are currently gaining importance through their monitoring in select areas in the country. There is ongoing research and dialogue, regarding specifications of emission related parameters, to include more pollutants under the preview of the National Ambient Air Quality Standards. Specifically regarding benzene, the CPCB in setting up the standard value and it would soon be included in the NAAQS.

Apart from the specification for criteria pollutants in ambient air, there have been category wise industrial emission specifications. These standards evolved under the Environment (Protection) Act, 1986. Specifications for fuel quality for motor vehicles, motor gasoline, and diesel fuel have also been specified.

The National Ambient Air Quality Monitoring Programme

The air quality monitoring programme in India was started in 1967 by the National Environmental Engineering Research Institute (NEERI). Monitoring was expanded to include regular monitoring at three stations in 1978. During 1984 and 1985, the Central Pollution Control Board (CPCB) established a network of seven monitoring stations for the National Ambient Air Quality Monitoring Programme (NAMP). This network has been expanded progressively and by March 1999, it comprised 290 stations covering over 90 towns and cities and distributed over 24 states and 4 union territories. Of the 290 monitoring stations, which include 30 stations managed by NEERI, 204 stations are presently operating. The 30 stations managed by NEERI are supported under the Global Environment Monitoring Systems (GEMS) and the data reported to CPCB, the United Nations Environment Programme (UNEP) and the World

health Organisation(WHO).In states such as Bihar, Haryana and Karnataka, fewer than 50% of the stations are in operation (CPCB 2000a).

The pollutants that have been historically monitored are sulphur dioxide, nitrogen dioxide and suspended particulate matter. In addition, NEERI monitors additional pollutants like ammonia, hydrogen sulphide, respirable suspended particulate matter (with an approximate cut-off size of 10µm) and polycyclic aromatic hydrocarbons. RSPM has also been recently added to the pollutants regularly monitored at many CPCB/SPCB monitoring stations. In Delhi, carbon monoxide, ozone, benzene and trace elements have been monitored only at a few locations by CPCB .Recently 8 new monitoring stations - two in the states of Gujarat, Maharashtra, Tamil Nadu and Uttar Pradesh-were established under a World Bank project.

In addition to the NAMP, air quality is also monitored by CPCB at various traffic intersections using a mobile van in Delhi. A few research institutes, NGOs, and others are also involved in monitoring. The air quality data generated by all these agencies may have certain limitations regarding the probability of variation, biases due to the involvement of large number of monitoring agencies, personal, equipment for sampling, analysis and data reporting. Moreover, the air quality data published are more indicative rather than absolute and perfect due to the aforementioned limitations.

As we know, that pollutants in the ambient air are contributed by many sources, of which automobiles are one. To accurately and convincingly state the percent contribution of emissions from various sectors, emission inventories are to be made, and source apportionment studies need to be conducted. Comprehensive emission inventories are limited to mega cities such as Mumbai and Delhi. Even these are sketchy due to the unavailability of data related to fuel use and suitable emission factors from various sources.

Status and trends of key pollutants

In a study by TERI, the air quality was rated in 62 Indian cities in 1994, and the analysis showed that the quality of air was dangerous or bad in 34 of the total 62 evaluated cities (Pachauri and Sridharan,1998). In this study, the Oak Ridge air quality index (ORAQI) methodology was used to rate the overall air quality. Air quality indexes are used so that a layperson or a decision-maker may understand the quality of the air. ORAQI categories are as follows: Excellent, Good, Fair, Poor, Bad and Dangerous.

This section gives an overview of the status and trends of some of the key pollutants like SO₂, NO₂ and SPM in select major cities. In the following

analysis, air pollution is said to be low (L) if the concentration of the pollutant is less than half of the notified standards (S) ($<0.5 \times S$), moderate (M) if it lies between half of S and S ($0.5 \times S - 1.0 \times S$), high (H) if it lies between S and 1.5 times S ($1.0 \times S - 1.5 \times S$) and critical (C) if more than 1.5 times S ($>1.5 \times S$). These have been followed from the set CPCB categories, which are based on the ratio of annual mean concentration of pollutant with that of respective air quality standard. If a city has more than one monitoring station, the location with the highest concentration has been considered. Table 2.6 provides a comparative analysis of SO_2 , NO_2 and SPM in major Indian cities for the years 1990, 1995, 1998.

Table 2.6 Levels of major pollutants (1990, 1995, 1998)

City	Pollutant	1990		1995		1998	
		R	I	R	I	R	I
Mumbai	SO_2	L	M	L	M	L	M
	NO_2	L	L	M	L	L	L
	SPM	H	M	C	M	M	M
Calcutta	SO_2	L	L	L	M	M	-
	NO_2	M	L	L	L	M	-
	SPM	H	M	C	H	C	-
Chennai	SO_2	L	L	L	L	L	L
	NO_2	L	L	L	L	L	L
	SPM	M	L	M	L	M	L
Bangalore	SO_2	L	L	N/A	N/A	M	L
	NO_2	L	L	N/A	N/A	M	L
	SPM	L	L	N/A	N/A	C	L
Delhi	SO_2	L	L	L	L	L	L
	NO_2	L	L	M	L	L	L
	SPM	C	H	C	H	C	M
Ahmedabad	SO_2	L	L	M	L	-	-
	NO_2	L	L	L	L	-	-
	SPM	H	M	C	M	-	-
Hyderabad	SO_2	L	L	L	L	L	L
	NO_2	L	L	L	M	M	L
	SPM	H	L	C	M	H	M
Howrah	SO_2	H	L	C	L	-	-
	NO_2	H	M	C	C	-	-
	SPM	C	H	C	M	-	-
Bhopal	SO_2	L	L	L	L	L	L
	NO_2	L	L	L	L	L	L
	SPM	H	H	C	L	C	H
Nagpur	SO_2	L	L	L	L	L	L
	NO_2	L	L	L	L	L	L
	SPM	H	M	H	L	M	L
Jaipur	SO_2	L	L	L	L	L	L
	NO_2	L	L	L	L	L	L
	SPM	C	M	C	M	H	M
Kanpur	SO_2	L	L	L	L	L	L
	NO_2	L	L	L	L	L	L
	SPM	C	H	C	H	C	H
Chandigarh	SO_2	L	L	ID	ID	L	L
	NO_2	L	L	ID	ID	L	L
	SPM	H	M	ID	ID	C	M

*N/A Data not available ; **ID Insufficient data

Source. CPCB 2000a

The above table reveals that:

- SO₂ levels are low or medium except at Howrah where the concentration is critical.
- NO₂ is showing an increasing trend in some of the cities
- The pollutant of concern in cities in India is particulate matter where the levels far exceed the NAAQM standards.

Comparative analysis of annual ambient air quality data of key pollutants for the year 1995 and 2000

Since, there has been considerable improvement in fuel quality and enforcement of stricter vehicular emission rules from 1996, the effect of such measures may be reflected in the air quality of later years and thus a comparative analysis of the annual ambient levels of SO₂, NO₂ and SPM during the year 1995 and 2000 has been done in this section and the cities which have exceeded the permissible limits have been mentioned. The analysis was done with the help of the published air quality data of 1995 by CPCB and the Mashelkar Committee report.

SO₂ Concentrations. SO₂ was found to be high (1-1.5 times the standard) in the residential areas of Dhanbad, Ahmedabad, Surat, Ankleshwar, Baroda and also the industrial areas of Ankleshwar, Surat, Pondicherry in the year 1995. However, in the residential areas of Surat and Howrah the annual average SO₂ concentration reached the critical (> 1.5 the standard) level, while in the rest of the cities monitored the level of SO₂ was found to be moderate to low. In the year 2000, the levels of SO₂ was found to be well within the permissible limits in all of the cities monitored. Thus, overall there was a downward trend with the exception of Cochin(Industrial area) and Pune where the level in SO₂ concentration increased to moderate in the year 2000 from low in 1995. The reduction in the level may have a relationship with the enforcement of stricter air quality norms for all pollution generating sources and the use of upgraded quality of fuels at anthropogenic pollution generating sources (Mashelkar Committee Report,2002).

NO₂ concentrations. Critical and high levels of NO₂ are seen in the ambient air quality data for the year 1995 in cities of Jabalpur, Alwar, Kota, Howrah (Residential-212.2µg/m³) and Pondicherry. The problem may be due to the combined effect of vehicular and industrial pollution since these cities form the highly urbanised and industrial pockets of the country. Ambient air quality

results for the year 2000 showed higher concentration of NO₂ in the residential areas of Delhi and Pune. Both residential and industrial areas of Alwar reported higher concentration of NO₂. In rest of the cities monitored, NO₂ levels were found to be within the permissible limits. An increment in the levels of NO₂ in cities of Ahmedabad, Cochin, Nagpur, Pune, Raipur, Alwar and Kanpur were observed in the year 2000 in comparison to 1995, while a few cities like Hyderabad, Dhanbad, Jabalpur, Nagda, Udaipur, Howrah and Pondicherry showed a downward trend. Overall there has been a reduction in the number of non-attainment cities in the year 2000 (three cities) in comparison to 1995 (six cities) (Mashelkar Committee Report, 2002).

The problem of NO₂ and SO₂ in the urban cities may also be aggravated due to inadequate power supply for industrial, commercial and residential activities due to which consumers have to use diesel based captive power generation units emitting high NO₂ and SO₂ emissions (CPCB, 2000a).

SPM concentrations. Annual ambient air quality data for the year 1995 shows exceeding levels of SPM in most of the cities that were monitored. Ten locations in the Industrial areas showing critical levels are Amausi Airport in Lucknow; Rajkot in Gujarat, Cossipore in West Bengal; Shahdra, Nizamuddin and Ashok Vihar in Delhi; Basni Industrial Area, Jodhpur; Bhilai, Indore in Madhya Pradesh and Jharia in Jharkhand. Out of the 56 cities, monitored SPM levels were critical in 27 cities and high in 10 cities. SPM data for the year 2000 shows critical level in the cities of Jalandhar, Ludhiana, Alwar, Indore, Agra, Dehradun, Kanpur, Solapur, Bangalore, Damtal, Dhanbad, Jamshedpur, Patna and Delhi. Out of 60 cities monitored 14 cities reported critical levels of SPM, 12 cities reported higher level. Thus, there has been a downward trend when we compare SPM levels of year 1995 and 2000.

Trends in emissions of other critical pollutants

Apart from the regular monitoring of these three criteria pollutants at different locations in the country, regular monitoring of parameters like RSPM, CO, Ozone, Poly Aromatic Hydrocarbons and Benzene have been introduced in Delhi a few years back. The status of RSPM levels from March 1998 to December 1999 at Bahadur Shah Zafar Marg, Delhi indicate that 24 hourly RSPM values fluctuated between 56 µg/m³ to 820 µg/m³. The trends of RSPM closely followed the seasonal trend of SPM depicting 100% violations of 24 hourly Standard (150 µg/m³) between October 1998 to April 1999. This could be attributed to unfavourable seasonal conditions and critical persistence of temperature

inversion. The CO levels measured at the same location ranged between 2.7 mg/m³ to 5.6 mg/m³ (Standard being 2.0 mg/m³ at residential areas). Similarly, the maximum values of hourly Ozone concentration ranged between 26-104 µg/m³ against 1 hourly USEPA standard of 235µg/m³ indicating that the ambient ozone values have been well within the prescribed standard limits. Since Ozone is expected to build up in sub-urban areas or places away from traffic corridors because of the ability of O₃ and its precursors to travel long distances, the levels monitored at traffic intersections may not be a true reflection of actual situation and may mislead that Ozone is not a problem in India. This has to be verified in future monitoring of Ozone at sub-urban places away from traffic corridors.

A analysis is underway with respect to data obtained from traffic intersections in Bombay, Calcutta and Delhi. This would be analysed and the results presented to possibly link critical pollutants from traffic intersections, their seasonal variation and the general status of air quality.

Growing automobiles and vehicular emissions

The increasing usage of the world's fossil fuels has lead to serious air pollution problems. Among the many sources of pollutants, the transportation sector is considered as the single major source in urban areas in most Asian countries (UNEP 2002). The transportation sector contributes to pollutants such as lead, carbon monoxide (CO), nitrogen oxides (NO_x), benzene, air toxics, particulate matter (PM), sulphur dioxide (SO₂) and ozone (O₃). Specifically, the four main hazardous toxic air pollutants from mobile sources have been identified as benzene, 1,3 butadiene, acetaldehyde and formaldehyde. Though most countries in Asia are known to have a low per capita vehicle ownership, the pollution load from the transportation sector is the highest.

Air pollution effects of the Asian region have been particularly significant with most countries having high levels of pollution – with the main pollutant of concern being PM. It has been estimated by the UNEP, that 12 of the 15 mega cities with the highest levels of particulate matter are located in the Asian region (UNEP 2002).

Emissions from diesel run vehicles contribute to particulates (black smoke) containing of carbonaceous matter along with various other compounds such as un-burnt hydrocarbons, polycyclic aromatic hydrocarbons, residue of lubricating oil additives, reaction products of SO₂ and NO_x sulphuric acid etc. Diesel powered vehicles also emit some of the aldehydes with highest share of

formaldehyde followed by acetaldehyde and others which comparatively less in the emissions (Table 2.8)

In terms of emissions of some of most important unregulated pollutants from the transportation sector like benzene, 1,3 butadiene, acetaldehyde and formaldehyde, their emissions are significant and these are from both diesel and gasoline fuels. Figure 2.1 shows average distribution of toxic air pollutants, estimates are valid for the US for gasoline with benzene content between 1 and 1.5 percent.

Table 2.7 Proportions of the major aldehydes present in exhaust gases from diesel engine

Type of products	Concentrations (in relative values)
Formaldéhyde	100
Acétaldéhyde	33
Acrolein	20
Butaldehyde	11
Propionaldehyde	8
Crotonaldehyde	8
Benzaldehyde	3
Tolualdehyde	1
Others	2

Source. Guibet 1999

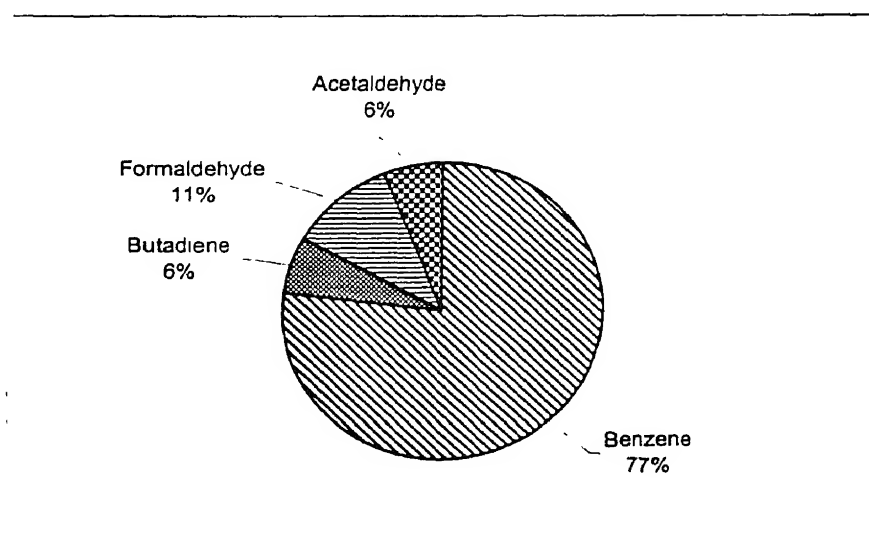


Figure 2.1 Average distribution of toxic air pollutants from US Gasoline

Source. (Guibet, 1999)

Uncontrolled diesel engines with poor diesel quality emit approximately 30-70 times more particulate than gasoline fuelled engines, which are equipped with catalytic converters (Kush, 2001). These particles are small and respirable (less than $2.5\ \mu\text{m}$) and consist of a solid carbonaceous core on which myriad of compounds get adsorbed. These include unburned, oxygenated and polynuclear aromatic hydrocarbons; inorganic species such as SO_2 , NO_2 and sulphuric acid. It has now been well established that diesel particulate matter represents a serious health hazard in many urban areas around the world. The World Health organisation has concluded that diesel particulate is a probable human carcinogen.

India

In India, the number of motor vehicles has increased from 0.3 million in 1951 (Pachauri and Sridharan, 1998) to 40.93 million in 1997 (CSO, 2001). At the all-India level, among the various modes of transportation, the percentage of two-wheeled vehicles in the total number of motor vehicles increased from 9 percent in 1951 to 69 percent in 1997 (Figure 2.2) and the share of buses declined from 11 percent to 1.3 percent during the same period (MoEF 2001).

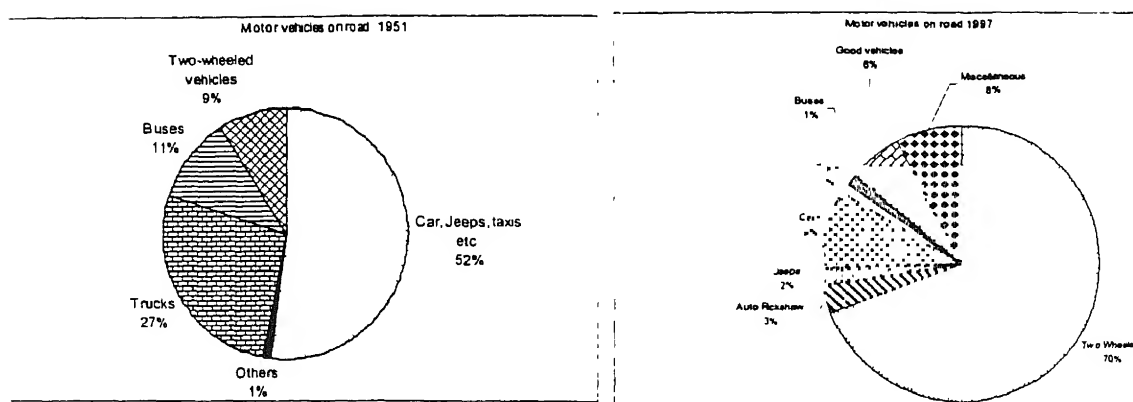


Figure 2.2 Comparative charts of motor vehicles in 1951 and 1997

The sectoral contribution of air pollution in Delhi as a percentage contribution for the year 2000-01 shows that 72% of air pollution in the capital is from the transportation sector followed by the industrial sector of 20% (Source: <http://envfor.nic.in/divisions/cpoll/delpolln.html>). This is a representation of the scenario that is existent in most metropolitan cities of the country. The combustion of transportation fuels like petrol, diesel etc contribute to various pollutants and it points out that petrol and diesel vehicles contribute to

almost 57 and 29% (i.e. total of 86% from the transportation sector alone) of the total emission load for a city like Mumbai (Figure 2.3).

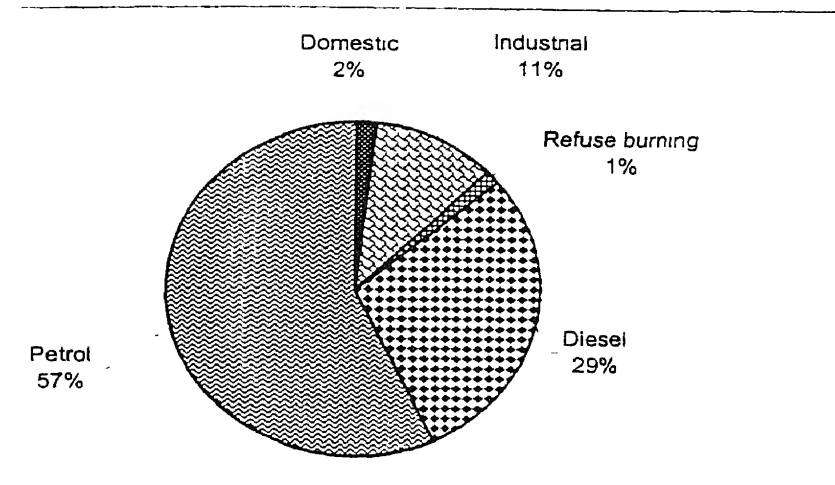


Figure 2.3 Emission load of Mumbai city (tonnes/day) and sectoral contribution (2000-01)

Source. Municipal Corporation of Greater Mumbai (Environmental Status report 2000-01)

In India, the emission load from the transportation sector alone is projected to increase in terms of all the pollutants such as carbon monoxide, hydrocarbons, SPM and SO₂. It has been identified that motor traffic is the most important source of PM in cities. The total emissions in terms of all the above pollutants is projected to rise from 13.32 to 57.16 million tonnes from 2000 to 2020 (Pachauri and Sridharan, 1998).

At the national level, regarding the quantum of vehicular pollutants emitted in major metros, it was the highest in Delhi followed by Mumbai, Bangalore, Calcutta and Hyderabad (MoEF 2001). In terms of the total pollution load, it has been observed that currently two wheelers contribute to the most of the pollution load (Figure 2.4).

The pollution load by different categories of vehicles in Andhra Pradesh shows a 56.2% share of the total vehicular pollution load by two wheelers, followed by 18.85 % share by trucks, 12% by four wheelers petrol driven (Figure 2.4). Two wheelers also contribute significantly to other pollutants.

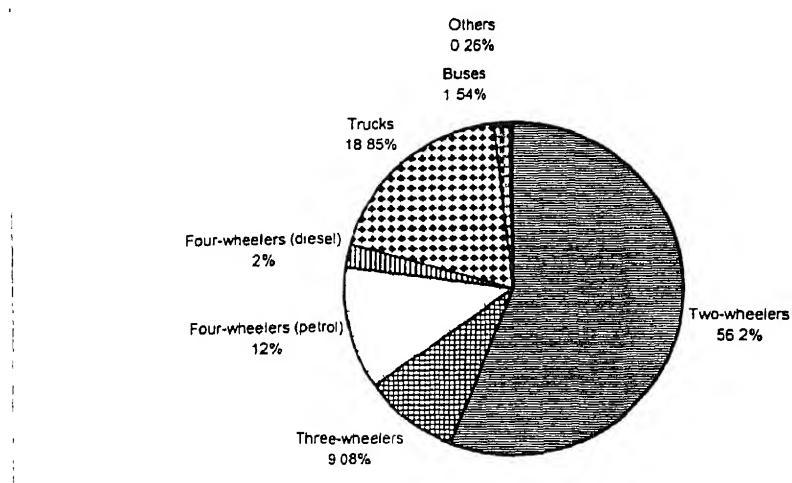


Figure 2.4 Pollution Load by different categories of Vehicles (% distribution) in Andhra Pradesh
Source. Survey of The Environment, The Hindu 2000

Air pollutants and their health impacts

Poor quality air has a considerable impact on human health. On a global basis, estimates of mortality due to outdoor air pollution run from around 200,000 to 570,000, representing about 0.4 to 1.1 percent of the total annual deaths (WRI, 1998). Most air pollutants in general have common symptoms like bronchitis, tightness in the chest, wheezing. Most of the short term or acute health impacts can be reversed if air pollution exposures decline.

The nature and extent of potential health effects that can result from exposure to air pollutants is dependent on a number of factors. These include,

1. Physical properties of the pollutant like shape, size, and solubility and vapour pressure.
2. Chemical properties and toxicity level
3. The genetic makeup, personal habits, age, sex, diet, health status and physical condition (fast breathing, exercise and running activities increase the amount of air inhaled) of the individual who is exposed to the pollutant
4. The concentration of the pollutant in the air, dose received by the individual, route and duration of exposure and the dose-effect relationship.
5. The various environmental factors like temperature, humidity, and presence of other contaminants and pressure differences.

Health effects with respect to epidemiological studies are used to establish linkages between exposures to air pollution and adverse health effects. Most of

the studies have been on particulates, which are the most severe and normally exceed standard values in many country studies. According to an estimate, out of a total of 8.2 million deaths in India, in 1989, anywhere between 0.9 and 3.6 million could be attributed to particulate air pollution (Pachauri & Sridharan, 1998). It is also estimated that 40% to 60% of pre-school children and 25% to 30% of women in the reproductive age suffer from chronic lung diseases (Pachauri and Sridharan, 1998). The annual loss in India due to the adverse effects of air pollution in human health is estimated at Rs 885 to Rs 4250 billion (Pachauri and Batra, 2001).

Despite the magnitude and urgency of air pollution as a public health issue, scientific understanding of health risks from air pollution in Indian cities is poor, and there is a paucity of scientific studies on the health effects. Specific studies that have been undertaken internationally and nationally relating to the effects of various pollutants on the health of human and a list of studies so far undertaken is attached in Annex 2.4. These studies show much cause for alarm. However in general, there is lack of data across the casual chain of risk assessment from sources of pollution to atmospheric concentrations.

Air pollutants and health studies in India

In India currently there have been a few case studies on the health effects of particulates. Summary of these studies are given below:

1. A study was carried out by AIIMS to correlate the daily levels of various pollutants with the number of patients visiting casualty for aggravation of certain defined cardio respiratory disorders. Daily counts of patients visiting the emergency room of the AIIMS for acute asthma, acute exacerbation of chronic obstructive pulmonary disease (COPD) was obtained from January 1997 to December 1998 and daily mean levels of ambient carbon monoxide, oxides of nitrogen and sulphur dioxide were monitored along with temperature and humidity. Results showed that ambient levels of pollutants exceeded the National Ambient Air Quality Standards on most of the days over the two year period and emergency room visit for Asthma, COPD and acute coronary events increased by 21.3%, 24.9% and 24.3% respectively on account of higher levels of pollutants. (CPCB 2001a)
2. In another study by Patel Chest Institute, New Delhi, the respiratory symptoms and lung functions of welders in Delhi was studied. The general symptoms of these workers due to exposure during work were heaviness in chest, eye irritation, passage of black sputum in morning, throat irritation nasal irritation and Nausea. Chronic bronchitis was diagnosed in 25% of the

- welders and was observed that longer duration of exposures would lead to more chances of developing chronic bronchitis (CPCB 2001a)
3. In another study by AIIMS- a health survey on individuals in residential areas of Delhi was carried out in 1997-98. The study pointed out that the most common symptoms related to air pollution was irritation of eyes (about 44.4% of the subjects surveyed suffered), cough (28% suffered) and Pharyngitis (16.5%), dyspnea (16% suffered) nausea (10% suffered) and respiratory problems (5.95% suffered). Normal lung functions were also much lower (CPCB 2001a)
 4. A study to determine effects of particulate matter on daily mortality in Delhi was conducted by the World Bank. The study showed that a positive and significant relationship exists between particulate pollution and daily non-traumatic deaths and deaths due to respiratory and cardiovascular problems.
 5. Biomonitoring of air pollution and health effects was done by Chittaranjan National Cancer Institute and Kolkata University for West Bengal Pollution Control Board during 1998-2000. This study looked into the respiratory symptoms, impairment in lung function, marked rise in Alveolar macrophages, abnormal sputum cytology, activation of secretory function of alveolar macrophages, abundance of iron-laden alveolar macrophages, augmentation programmed cell death, genotoxic effect, hematological changes, metabolic disorders, behavioural and hormonal changes. The study was conducted through data gathering through a questionnaire and medical examination to 1310 individuals from Kolkata and 200 from rural West Bengal.

Kolkata study findings

The study pointed out that there is a substantial increase in symptoms for both upper and lower respiratory tract diseases. Respiratory symptoms were found to be more frequent in winter when pollution levels of the city with respect to RPM were highest. However, the frequency of symptoms during monsoon was greater than that of summer despite lowest RPM level during monsoon. This may be due to greater proliferation of microorganisms as a result of higher humidity.

With respect to impairment of lung function, the assessment was done by spirometry in selected urban groups – street hawkers, garage workers, office employees and students. About 47% individuals showed impaired lung function. The study also revealed that persons with high exposure levels to automobile

exhausts like street hawkers and garage workers displayed severe impairment in lung function and the changes appeared to be related to age and length of exposure.

The study also revealed that the percentage of individuals with impaired lung function (47%) correlated well with the frequency of lower respiratory tract symptoms (47.8%) in urban people. Thus, it clearly shows that chronic inhalation of the city's air causes decline in lung function in a significant percentage of the inhabitants of the city.

Apart from the increase in Alveolar Macrophages (AM) count which was due to exposure to indoor air pollution and smoking, the study also found that there was an increase in AM count and that it had a close parallelism with the city's RPM levels (highest in winter, lowest in summer and medium in monsoon). The AM also showed a direct relationship with the degree of exposure to urban air pollution. Individuals exposed to high level of vehicular emission like traffic policemen, drivers, street hawkers, garage workers had higher AM than less exposed individuals (employees, housewives, students).

The study revealed that the city residents of Kolkata have 3.6 times more abnormal sputum cells compared to the rural individuals. This also had a clear correlation with exposure to emissions – vehicular and urban air pollution. Pollution exposed individuals in fact showed the presence of aberrant cell types, which leads to fibrosis of the lungs.

It also pointed out that persons exposed to combustion fumes and vehicular emissions of the city displayed a sharp rise in the frequency of mutation in cells lining the oral cavity. Increased rate of mutation enhances among others the risk of cancer. The study also pointed out that one third of the urban males had low hemoglobin value and morphologically abnormal red cells were found in blood of half of the urban individuals examined. The frequency of these abnormalities was much less in the rural group. Metabolic disorders were also seen in highly exposed individuals namely one third of the traffic police men and one fifth of street hawkers of the city were hyperglycemic (lower than normal blood glucose level). Kidney functions were also seen to be abnormal among substantial section of the policemen and firefighters of the city. In the same study, over 90% of the firefighters and 75% of traffic policemen who were engaged in outdoor duty for the last five years or more complained of headache, dizziness and irritation in the skin and eye (CPCB 2001a).

Literature review on health damages and costs

Air pollutants have severe health implications. Worldwide WHO estimates that as many as 1.4 billion urban residents breathe air that exceeds WHO guidelines (WRI, 1998). Of all pollutants, particulates, are said to have severe health impacts and hence studies have been primarily focused on them. An assessment of health damages from exposure to the high levels of particulates in 126 cities worldwide where the annual mean levels exceed $50 \mu\text{g}/\text{m}^3$ reveals that these damages may amount to near 130,000 premature deaths; over 500,000 new cases of chronic bronchitis and many more lesser health effects each year (Lvovsky, 1998). Each episode of illness caused by or made worse by air has direct and indirect economic consequences for individuals and society. They range from the costs of medical care through costs due to absence from work, to the loss of healthy years of life. Thousands of people have been exposed to the risk of chronic bronchitis and other respiratory diseases with varying degrees of inflictment.

Developed world

In the US, an estimated 80 million people live in areas that do not meet the US air quality standards, leading to 50,000 to 120,000 deaths annually and costs US\$ 50 billion (WRI, 1998).

Numerous studies have been undertaken in Europe to determine the impact of car emissions on human health and the environment. In Europe, the 1999 WHO report on health costs due to road traffic-related air pollution revealed that car-related pollution kills more people than car accidents in the three European countries (Austria, France, Switzerland) where the study was undertaken. The main findings of this study are:

- long-term exposure to air pollution from cars in adults over 30 years of age caused an extra 21,000 premature deaths per year from respiratory or heart disease. This is more than the total annual deaths from road traffic accidents in the countries studied (9,900).
- each year, air pollution from cars causes 300,000 extra cases of bronchitis in children, plus 15,000 hospital admissions for heart disease, 395,000 asthma attacks in adults and 162,000 attacks in children.
- a net cost from human health impact equivalent to 1.6 % of the GNP of Austria, France and Switzerland .

A tri-nation study involving Austria, France and Switzerland assessed the external public health costs of total air pollution and of traffic related air pollution. The results of the study are summarised in Table 2.8.

Table 2.8 Health costs due to PM₁₀ emissions

Country	Year of study	Method of economic valuation	Health cost due to air pollution (million Euro)	Health cost due to transportation (million Euro)	Mortality cost due to air pollution (million Euro)	Morbidity cost due to air pollution (million Euro)
Austria	1996	WTP*	6700	2900	5000	1700
France	1996	WTP	38900	21600	28600	10400
Switzerland	1996	WTP	4200	2200	3000	1600

*Willingness to pay

Source. <http://www.eehc.dk/London99/traffic.htm>

In terms of health effects of particulates, however there are significant uncertainties about the source contributions to total ambient small particles. In the Concauwe review report, it has been elaborated that, in the UK 25 percent of PM₁₀ and 60 percent of PM_{0.1} emissions are reported to come from road transport (CONCAWE, 1999b). However a recent study in the US has suggested that 8- to 90 percent of primary particulate emissions are fugitive dust with only 3-9 percent contribution from automotive exhaust emissions (CONCAWE, 1999b). In a study in Australia reports that automotive exhausts account for 13 percent of PM₁₀ and 6 percent of primary PM_{2.5} (CONCAWE, 1999b).

Developing world

The human cost of particulate air pollution in the developing world is staggering. In Latin America, about 81 million city residents i.e more than one quarter of all city dwellers are exposed to high levels of air pollution resulting in 65 million days of illness each year (WRI, 1998). In Latin America, more than one quarter of all city dwellers are exposed to high levels of air pollution and it results in the annual loss of some 65 million working days (WRI, 1998). In South Asia, acute respiratory illness deaths are reported to be as large as 1.4 million per year (UNEP 2002b).

Around 500,000 premature deaths annually in India occur due to indoor air pollution (Smith, 2000). A study concluded that about 270,000 Indian children under the age of 5 die per year from acute respiratory infections arising from particulate air pollution. A report of US energy administration has estimated that health costs due to air pollution in Pakistan is about 500 million US \$ per

year. (<http://lists.isb.sdnpk.org/pipermail/health-list/2001-February/000329.html>)

Economic valuation of the health impacts due to air pollution

There are a vast majority of epidemiological studies that have looked at associations between mortality and morbidity endpoints and air pollution due to outdoor air pollution measurements mainly in the industrialized countries. The human exposure levels linked to observed human health effects have traditionally been characterised by dose-response curves or exposure response curves. The total daily exposure of an individual to air pollution is the sum of the separate contacts to air pollution experienced by that individual when he/she passes through a series of environments (micro environments) during the course of the day. Exposures in each of these microenvironments can be valued as the product of the concentration of the pollutant and the time spent in the environment.

Methods of estimation of health costs

Understanding the complex interactions involving human activities, air pollution emission, atmospheric transport, chemical transformation of pollutants, human exposure risk factors and health response and economic damage is a daunting challenge. To understand the adverse effects of air pollution in terms of economic costs, cost values are attributed to the damages caused. Economic ramifications of air pollution on health is important for policy intervention and for health care professionals, public policy decision makers, and the general public in understanding the issues in terms of public health issues.

Impacts of pollutants on human health are normally grouped into categories of premature deaths, mortality, hospital admissions, emergency room visits, doctors office visits and minor illness. Economic damages corresponding to these morbidity (illness)/ mortality are forecast according to discrete components:

- Value of loss of life (rising premature deaths etc)
- Value of quality of life (e.g. increasing pain, suffering from illness)
- Health care cost and loss of productivity (i.e. lost time, wages)

The costs of morbidity may be subdivided by two main criteria, namely the cost component and by the entity in charge of paying them. The costs of illness, the cost of averting behaviour and the intangible costs are three different

components. They are either borne privately or collectively. The different methods of estimation of health costs and health responses and economic damages are detailed in Table 2.9.

The cost of averting behaviour and intangible costs are difficult to measure, the cost of illness approach is used to value morbidity due to air pollution. Since this is a partial assessment of morbidity costs, willingness to pay approach to measure morbidity costs is more preferable. This method focuses on the individually borne costs and establishes the individual's utility of risk reduction in air pollution related morbidity and reflects all costs the individual expects to bear in case of disease, such as loss of earnings, cost of averting behaviour or intangible costs. For the monetary valuation of mortality, the two approaches that may be used are - the gross production/ consumption loss and the Willingness to pay approach. In the former approach, the costs of additional mortality cases are based on the loss in income/ production or the loss of consumption.

Table 2.9 Methods of valuation: air pollution

Method	Brief description
Cost of Illness (COI)	It contains the loss of production due to a possible incapacity to work and the medical treatment costs. They determine the "material part" of the health costs and may be assessed on the basis of real market prices.
Cost of averting behaviour	It results from a different behaviour due to air pollution. The abstention from outdoor sport activity during a day when visibility is less due to high levels of air pollution, the installation of air filters or a different choice of residential location are all examples of averting behaviour.
Intangible costs	It reflects the individual loss of victims utility and consist of pain, grief and suffering due to a disease.
Willingness to pay (WTP) / Value of preventing a statistical fatality (VPF)	In this approach the willingness to pay for the avoidance of a statistical case of mortality or "the value of preventing a statistical fatality" is assessed.

Economic loss due to air pollution

Health impacts being the largest portion of all social costs attributed to environmental damages due to air pollution, economic valuation of health impacts is of prime importance. The cost numbers show a significant amount of loss on the GDP of a country due to the impacts of air pollution. This can be averted through effective policy measures in terms of cleaner fuels, efficient vehicles along with effective measures to reduce pollution (World Bank 1998).

Table 2.10 summarises the economic loss due air pollution in a number of countries.

Table 2.10 Economic loss due to air pollution

Country	Method	Externality costs due to air pollution	Year	Source
Austria	WTP	3.8% of GDP	1996	http://www.eehc.dk/London99/traffic.htm
France	WTP	3.2% of GDP	1996	-do-
Switzerland	WTP	2.1% of GDP	1996	-do-
Hong Kong	WTP (morbidity and mortality costs)	0.51% of GDP	1996	http://www.gov.hk/epd/english/environment/hk/air/study/rpts/effect_econ_amb_ap.html
	COI (morbidity and mortality costs)	0.35% of GDP	1996	-do-
China	-	5% of GDP	1998	http://www.earth-policy.org/Updates/Updates17.htm
China	DALY*	12%(GDP/capita)	1998	Kseniya Lvovsky, World Bank ,1998
India	DALY	9%(GDP/capita)	1998	Kseniya Lvovsky, World Bank ,1998

* DALY: Disability Adjusted Life Years

Conclusions and recommendations

The analysis of ambient air quality data of India for various years suggest that:

- SO₂ is low in most of the Indian cities as they are well within the National Ambient Air Quality Standards
- PM is the pollutant of concern in the Indian cities. For health point of view fine particulates (PM_{2.5} or less) are very important. But at present PM_{2.5} monitoring is not done even in major cities. The future monitoring programme should include fine particulate matter monitoring.
- NO₂ shows an increasing trend in some of the Indian cities though the annual average concentrations may be well within the permissible limits. As NO₂ is a one of the major pollutant from transport sector, with the increasing trend in vehicular population this increasing trend in NO₂ may likely to continue in the future. This indicates the need for stringent NO_x control measures to be adopted especially from the transport sector.
- Measured Ozone concentrations have generally been found to be low in Indian cities till date, but the data is limited as far as the number of monitoring stations are concerned and the methods adapted for its analysis.
- Levels of Benzene measured have been found to be high by international standards. Vehicular emissions are found to be the main source of Benzene in the few studies done in India by various researchers.
- In addition to the regular monitoring of criteria pollutants, there is a need for monitoring various toxic such as benzene, formaldehyde, 1,3 butadiene and acetaldehyde etc in the ambient air.

- More epidemiological studies both for chronic and acute exposure of air pollutants are needed to be undertaken in developing countries situation. More studies related to the estimation of health costs should be undertaken in developing countries situation.

Analysis and review of studies and papers on the exposure to air pollutants and health points out that air pollution has significant impacts on human health. Most epidemiological studies have looked at the associations of mortality and morbidity endpoints of air pollution (Panyacosit, 2000). From a review of existing papers, it is observed that there is a clear evidence of the relationship between exposure to particulate matter and health. In general the studies on particulates are varied in terms of the component of the particulate studied, some are on PM/ TSP, PM₁₀ or PM_{2.5} and the type of the study vary by either being acute or chronic and hence the results are difficult to compare. A majority of research and existing literature indicate the studies have concentrated on particulates especially on the PM₁₀ fraction and its health effect.

Studies do however show considerable consistency in the correlation between exposure to particulate pollution and mortality. The epidemiological studies conducted so far show strong evidence of correlation between PM measurements and respiratory disease/mortality and associated hospital admissions. There is moderate evidence which shows association between cardiovascular diseases and PM. Studies in China, looking at morbidity related health end points found associations between high levels of particulate pollution and increased daily hospital admissions, non surgery visits, where association increased 1.5 to 2.0 fold for specific departmental visits e.g. pediatric and internal medicine visits (Panyacosit, 2000).

It has not been possible to discriminate between the adverse health effects caused by particles and those caused by other air pollutants which can cause similar effects (ozone, SO₂, NO₂, and CO) and other factors such as changes in temperature and humidity.

Most of the dose-response studies have been conducted in industrial countries. Hence extrapolation of the results for developing countries is made from exiting results. The question of validity of this procedure hence comes into doubt. However there have been studies in developing countries such as Mexico, Santiago, Chile, Bangkok and Thailand and comparisons of these studies do provide information on the percent change in mortality due to absolute change in ambient particulate matter (Lvovsky, 1998). However to determine the number of excess (prevented) cases of death due to exposure to

higher (lower) concentrations of particulates, the present change and the baseline rate in the impacted area, must be determined. Hence extrapolation of data from developed countries is reasonable but baseline differences should be acknowledged and if possible accounted for (Panyacosit, 2000)

In terms of health costs, though the figures in terms of death, morbidity and mortality due to pollutants have been estimated in numbers, it is difficult to correlate the effects of the various pollutants and their individual effects. Especially relating studies to particulates, due to the lack of measured data, and the limited accuracy of the methods used to estimate personal exposure, the real potential of particulates due to indoor level, out door and from smoking and their effects are difficult to estimate. In general estimating costs are based on process with bias and assumptions and there is no single method of measuring health cost associated with air pollution (Panyacosit, 2000). Comparison of estimates of costs from varied countries is also difficult.

Annex 2.1 Regulated pollutants

Pollutants	Causes/remarks	Sources	Total worldwide anthropogenic emissions	Emissions from the transportation sector	Health effects
CO	Incomplete combustion of carbonaceous fuels due to lack of oxygen supply	Anthropogenic sources: Vehicular sources. Thermal power plants Heating for industrial facilities, and incinerators. Minor sources Solid waste disposal sites and Refuse burning	In 1995, 350 million tons, 59% of which contributed by the transportation sector alone.	The USEPA (United States Environmental Protection Agency) has estimated that about 70% of CO emissions are from transportation sector with almost all of that coming from vehicles (USEPA 1998).	CO is absorbed through the lungs. It reduces the blood's capacity to transport available oxygen to the tissues. Lowers the oxygen level in blood. CO uptake impairs perception and thinking Slows reflexes, may cause drowsiness, angina, unconsciousness or death (WB 1997)
NO _x	NO and NO ₂ together are generally expressed as NO _x . Their emissions are governed by 1) Availability of oxygen and 2) High temperature NO gets oxidised in the atmosphere to form NO ₂	Anthropogenic sources: Fuel combustion in motor vehicles, Power stations and furnaces	World-wide anthropogenic NO _x emissions for 1995 were estimated at 93 million tonnes	(43 %) of this or 33 million tonnes attributed to be from the transportation sector	It is absorbed into the mucous membrane of the respiratory tract. Exposure to NO ₂ is with increased susceptibility to respiratory infection, increases airway resistance in asthmatics and decreases pulmonary function. Possible increase in acute respiratory infections and bronchitis morbidity in children. Produce brown haze in city air. Causes corrosion
SO ₂	SO ₂ emissions are linked to the sulphur content of the fuel. Hence, SO ₂ gases are formed when fuel-containing sulphur, such as coal and oil, is burned. They are also formed in petroleum refineries, cement manufacturing and metal processing facilities.	Anthropogenic sources: Burning of sulphur containing fuels like coal and oil Non combustion sources: Industrial facilities that derive their products from raw materials like metallic ore, coal, and crude oil.	Over 65% of SO ₂ released to the air, more than 13 million tons per year, comes from electric utilities, especially those that burn coal.	The transportation sector alone at a global level contributes to about 2 to 6 percent of the global SO ₂ emissions. (WB 1997).	Combined with smoke, increase risk and effects respiratory diseases. Causes suffocation and irritation of throat and eyes.

Pollutants	Causes/remarks	Sources	Total worldwide anthropogenic emissions	Emissions from the transportation sector	Health effects
(Pb)	tetramethyl lead, used as an anti-knock agent in petrol is released into the atmosphere as fine particles when petrol is burnt. Other sources	Anthropogenic sources: Emission from motor vehicles, lead smelters, waste incinerators, utilities and lead acid battery manufacturers.	-	-	Adversely affects the human nervous system. Causes anaemia, brain dysfunctions and kidney damage.
O ₃	Mainly derivative. products of atmospheric reactions between other pollutants. Ozone is a natural and essential constituent of the upper atmosphere.	Emissions from motor vehicles. Photochemical reactions of nitrogen oxides and reactive hydrocarbons			Cause eye irritation and impaired pulmonary function in diseased persons. Causes materials and reduces visibility. Ozone is one of the most damaging pollutants plants

Particulates

Pollutants	Description	Source	Health effects and remarks
Particulates	Any dispersed matter, solid or liquid, in which the individual aggregates are larger than single small molecules (about 0.0002µm in diameter), but smaller than about 500µm. Extremely diverse and complex due to wide range of sizes, chemical composition and atmospheric concentration.	Anthropogenic sources of particulate matter (PM) include Thermal power plants, industries, commercial and residential facilities, construction sites, stone crushing, burning of wood, motor vehicles using fossil fuels. Natural sources Wind-blown soil, dust from tilled fields, unpaved roads etc. volcanic ash, Forest fires, sea salt and pollen	The harmful effects, if any, of the particles depend on their chemical and mineralogical composition, solubility and biological activity. Known to cause bronchitis and respiratory related illnesses. Low birth weights have been established as a risk factor for acute respiratory infections. A study in China indicates that chronic exposure to air pollution can impair lung function in non-smoking adults
SPM/ TSP	Suspended Particulate Matter or Total Suspended Particulates are particulates that have diameter less than 100µm. Tend to settle near their emission source.	Anthropogenic sources: Contribution arising from fossil fuel burning, industrial processes Vehicular pollution Natural sources Sea salt, soil dust, volcanic particles and smoke from forest fires and	
RSPM or PM₁₀	Particulates having diameter 10µm or less. PM ₁₀ remains longer in the atmosphere because of its low settling velocity.	Have their origin from road dust, vehicular exhausts (diesel and petrol vehicles), wind blown dust, agriculture, construction and fireplaces.	PM ₁₀ have their primary source linked to the transportation sector where the particulates emissions are less than 10 µm. Increased vehicular population have shown

Pollutants	Description	Source	Health effects and remarks
			an increase particulates They can get deposited in the extrathoracic part of the respiratory tract through nasal breathing.
Fine * Particulates	Particulates having diameter 2.5 μm or less are termed fine particulates	<p>Formed by various processes</p> <p>Particles in the 0.005 - 0.05 μm ranges are usually formed by condensation of vapours at high temperature or chemical processes</p> <p>Particles in the 0.05-2 μm range are usually formed by coagulation of smaller particles.</p> <p>PM_{2.5} are emitted from fuel combustion in motor vehicles, process combustion and from industrial sources; residential and agricultural burning.</p> <p>PM_{2.5} from chemical reactions that involve such gases as SO₂, NO_x and VOC.</p> <p>Result of solidification of volatile metal salts as crystals following cooling of hot exhaust gases from vehicles in ambient air (Winchester 1989)</p> <p>PM_{2.5} may also be formed from sulphates, which generated by conversion from primary sulphur emissions.</p>	<p>Particulates in the size range between 2.5 μm to 10 μm get deposited near the fine airways</p> <p>PM 2.5 can evade human respiratory systems defence system and reach lung tissue and soluble particles be absorbed into the blood system.</p> <p>The effects seen with it are pneumonia, asthma, and bronchitis</p>

Note: * PM₁₀ and coarse particles synonymous terms both refer to PM with diameter of less than or equal to 10 μm . PM 2.5 and fine particles both refer to size ranges less than or equal to 2.5. The ultra fine particles with diameter less than 0.1 μm . The distinction between coarse and fine particles is made due to the difference in sources, formation mechanism, composition atmospheric life times, spatial distribution etc. The concentration of particulates differ across regions which is based on the sources and concentrations and the residence time which translates its transboundary effects.

Annex 2.2 Some unregulated pollutants

Pollutants	Description	Source	Health effects and remarks
Hydrocarbons	<p>Group of compounds consisting of carbon and hydrogen. In air quality studies, the term hydrocarbon is extended to include a variety of other volatile organic compounds (VOCs) such as alcohols and aldehydes.</p> <p>Several hundred different hydrocarbons (e.g. methane, ethane, ethylene, pentane, benzene) have been distinguished with detailed proportions depending on combustion conditions</p>	HC emissions from motor vehicles occur from unburned fuel or from partial combustion of fuel	<p>Most hydrocarbons are not directly harmful to health at concentrations found in the ambient air</p> <p>When they undergo chemical reactions (except methane) in the troposphere they form O_3 and NO_2 which are considered as health and environmental hazards.</p>
Toxic hydrocarbons	Benzene, 1, 3-butadiene, aldehydes and polynuclear aromatic hydrocarbons are few of the major toxic HCs emitted by motor vehicles		This group represents about 8 percent of the global emissions of VOCs and are mutagenic in nature
a) Benzene	Benzene in exhaust originates directly as it is present in gasoline as well as from partial combustion of aromatic compounds present in gasoline like Xylene and Toluene	<p>Emissions from manmade sources are significant</p> <p>Direct evaporative emissions and vehicular exhaust</p>	<p>Early manifestation of toxicity are anaemia, leucocytopenia or thrombocytopenia. It is a known human carcinogen</p> <p>Long term exposure causes leukemia. Exposures to benzene is linked to genetic changes, increased proliferation of bone marrow cells and occurrence of certain chromosomal aberrations. WHO estimates a 4 in 1 million risk of leukaemia on exposure to benzene to a concentration of $1\mu g/m^3$ (CPCB 2000b) According to the U.S EPA, roughly 70.2% of the total benzene emissions come from vehicles (World Bank 1990) Out of the total Benzene levels in air, about 85-90% of its emissions come from exhaust and the remainder comes directly from gasoline evaporation and through distribution losses (World Bank 1997)</p>
b) 1,3 butadiene	Formed in vehicle exhaust due to the incomplete combustion of fuel and is not present in vehicle evaporative and refuelling emissions.	Mobile sources account for nearly 94% of the total 1,3 Butadiene emissions (Kush 2001)	<p>Transformation of 1,3 butadiene in the atmosphere result in the formation of formaldehyde and acrolein, species which are themselves toxic and/or irritants. UK expert panel on air quality Standards has recommended 1ppb ($2.2\mu g/m^3$) as the rolling annual mean for butadiene. WHO air quality guidelines recommend a maximum concentration of $0.1mg/m^3$ (for a period of 30min)</p>
c) Formaldehyde	Not a component of evaporative emissions Formaldehyde exhibits	Vehicular exhausts gasoline and diesel	Aldehydes are absorbed in the respiratory and gastrointestinal tracts and

Pollutants	Description	Source	Health effects and remarks
	extremely complex atmospheric behavior. Though difficult to quantify, it appears that mobile source contribution of formaldehyde in the ambient air is approx. 30%.	fuelled vehicles Also formed by the atmospheric oxidation of virtually all organic species	metabolized. Adverse health effects include eye and nose irritation at a concentration of $0.06\text{mg}/\text{m}^3$. Irritation of mucous membranes and alteration in respiration, coughing, nausea, and shortness of breath. Threshold for tissue damage is about $1\text{mg}/\text{m}^3$ Occupational exposure to formaldehyde is associated with risk of cancer.
d) Acetaldehyde	Vehicle exhaust due to incomplete combustion of fuel. 40% of the acetaldehyde in ambient air may be attributable to mobile sources	Acetaldehyde is produced from combustion from vehicle exhaust, from coal refining, wood burning or other types of incomplete combustion, such as in smoke from cigarettes.	Acetaldehyde causes health effects from both short term or acute exposures, such as in spills, and also long term or chronic exposures, such as repeated occupational exposures. Individuals also react differently to different levels of exposure. Acute exposure to acetaldehyde by inhalation may cause irritation of the eyes, nose, throat and lungs. At higher exposures, there may be coughing, pulmonary edema and respiratory paralysis and death.

Annex 2.3 Ambient Air Quality Standards ($\mu\text{g}/\text{m}_3$) in India, WHO and other countries

Air pollutants	Time weighted average	WHO, 1999 ¹	India, 1994 ²			USEPA July 1997 ³	UK ⁴ 1997	Japan ⁵
			Industrial	Residential	Sensitive			
Oxides of nitrogen (NO_2)	Annual							
	Average	40	80	60	15	100	21 ppb	-
	24 hrs.	-	120	80	30	-	-	75-113
	1 hr	200	-	-	-	-	150 ppb	-
Sulphur dioxide (SO_2)	Annual							
	Average	50	80	60	15	80	-	-
	24 hrs.	125	120	80	30	365	-	-
	3 hr	-	-	-	-	1300	-	-
	1 hr	-	-	-	-	-	100 ppb	286
	10 min	500	-	-	-	-	(15 min)	-
Carbon monoxide (CO)	8 hrs	10000	5000	2000	1000	10000	10 ppm	-
	1 hr	30000	10000	4000	2000	40000	-	22900
	30 min	60000	-	-	-	-	-	-
	15 min	100000	-	-	-	-	-	-
Lead (Pb)	Annual							
	Average	0.5	1	0.75	0.5	1.5	0.5	-
	24 hrs.	-	1.5	1	0.75	-	-	-
PM ₁₀	Annual							
	Average	-	120	60	50	50	-	-
	24 hrs	-	150	100	75	150	50	100
SPM	Annual							
	Average	*	360	140	70	-	-	-
	24 hrs.	*	500	200	100	-	-	-
PM _{2.5}	Annual							
	Average	-	-	-	-	15	-	-
	24 hrs.	-	-	-	-	65	-	-
Ozone (O_3)	8 hrs	120	-	-	-	157	50 ppb	120
	1 hr	-	-	-	-	235	-	-
Ammonia#	Annual							
	Average	-	-	100	-	-	-	-
	24 hrs.	-	-	400	-	-	-	-

* No definite guidelines mentioned

ppm – parts per million; ppb – parts per billion

Source: CPCB 2000a

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- 3 USEPA, July 1997, EPA Office of Air Quality Planning & Standards, USEPA, Triangle Park, USA
- 4 United Kingdom National Air Quality Strategy, March. 1997, Department of Environment, The Scottish Office
- 5 Basic Law for Environmental Pollution Control 1969 in Morley L (Ed.) 1991, Clean Air around the World 2nd Ed. International Union of Air Pollution Prevention Association, Brighton

Annex 2.4 Summary of epidemiological studies of the health effects of air pollution in children

Source Study location	Subjects	Exposure ^a	Health outcome ^b	Confounders controlled	Study design ^c period	Association ^d found
Aubry et al., 1989 Northeast France	Children aged 9-12; 375 exposed, 523 unexposed	Complex industrial pollution (dust, SO ₂ , NO _x , hydrocarbons)	Rhinitis, school absenteeism	Parental smoking; use of coal fires, parental education	Cross-sectional	Higher prevalence in exposed
Bobak & Leon, 1992 Czech Republic	Infants from 46 of 85 districts	PM ₁₀ , SO ₂ , NO _x	Total and respiratory mortality	Socioeconomic characteristics of districts	Ecological 1986-88	Postneonatal mortality associated with PM ₁₀ increase, Respiratory mortality (highest to lowest quintile OR) 1.2 for PM ₁₀ 3.9 for SO ₂
Braun et al., 1989 Switzerland	1225 children aged 0-5, in 4 areas (2 urban, 1 suburban, 1 rural)	NO ₂ , measured with personal samplers	Respiratory symptoms	Season, child's susceptibility to colds	Follow-up study (six weeks)	Association between outdoor NO ₂ and respiratory symptoms
Castillejos et al., 1992 Mexico City	143 7-9 yr old children, at 3 schools	Ambient O ₃	Respiratory function and acute respiratory symptoms		Follow-up study (six months)	O ₃ associated with 1% decrement in lung function for children, chronic phlegm
Dockery et al., 1989 Six US cities	Children from the Six Cities Study of Air Pollution and Health	TSP, PM ₁₀ , PM _{2.5} , FSO ₄	Chronic cough, bronchitis, chest illness		Cross sectional 1980-81 school year	Health outcomes positively associated with all measures of particulate pollution
Forastiere et al., 1992 Italy: One industrial town, one rural area, and the city of Rome	2929 primary school children	Outdoor air pollution and passive smoking	Respiratory symptoms and illness		Cross Sectional	OR for asthma 1.4 for industrial town and 1.1 for Rome (rural town as reference)

Source Study location	Subjects	Exposure ^a	Health outcome ^b	Confounders controlled	Study design ^c period	Association ^d found
Goren & Helleman, 1988. Ashod and Hadera, Israel	2 nd and 5 th grade schoolchildren	High and low air pollution areas	Respiratory symptoms and pulmonary diseases	Background variables	Cross sectional, Spring 1984	OR: 1.4 for sputum with cold and 1.8 for sputum without cold (high pollution area as compared with low pollution area)
Jaakkola et al., 1991. One polluted and two reference cities in Northern Finland	679 children 14-18 months; 759 children 6 years old	SO ₂ , particulates, NO _x , hydrogen sulphide (mainly industrial sources)	Respiratory infection	Potential confounders	Follow-up (12 month period, 1982)	OR: 2.0 in the younger group; 1.6 in the older group (polluted vs. less polluted).
Kinney et al., 1989. Kingston and Hamman, Tennessee	154 school children	O ₃	Transient lung function decrease (FVC, FEV ₇₅ , MMEF, V _{max75})		Follow-up. Two-month period beginning February 1981	Health outcome associated with O ₃ at levels below national standards
Kucerova et al., 1990. Slovakia	Children aged 7-14. 8973 in 1986; 9409 in 1987	Air pollution	Respiratory diseases		Cross-sectional	Higher annual incidence and higher mean duration in 11 contaminated areas
Melia et al., 1981a 28 areas of England and Scotland	Children aged 6-11 in 4 periods. 857, 1436, 2702 and 2036 children	Atmospheric smoke and SO ₂	Change in number of respiratory conditions between examinations		Follow-up 1973-77	Change in health unrelated to pollution levels
Mostardi et al., 1981. Akron, Ohio	Children in two schools (one next to industry)	SO ₂ , NO ₂ monitored daily	Acute respiratory illness		Follow-up	Higher incidence of cough, runny nose and sore throat in the polluted area
Ong et al., 1991. Two	Primary school children: 2009	Exhaust emission from	Respiratory symptoms	Gender, age, socioeconomic	Cross-sectional	Higher prevalence of sore throat, evening cough,

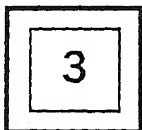
Source Study location	Subjects	Exposure ^a	Health outcome ^b	Confounders controlled	Study design ^c period	Association ^d found
districts in Hong Kong	from industrial area; 1837 from less polluted area	factories		factors, exposure to smoking	April/May 1989	cough for more than 1 month, morning phlegm and wheezing in polluted area
Penna & Ducharme, 1991. Rio de Janeiro	Infants	Air pollution	Infant mortality from pneumonia	Area of residence, income	Ecological 1980	Association between average annual level of particulates and mortality from pneumonia
Pope & Dockery, 1992. Utah Valley	Symptomatic and asymptomatic samples of 5 th and 6 th grade school children	Respirable particulate pollution (PM ₁₀)	Acute respiratory symptoms		Follow-up Winter 1990-91	Association between incidence of respiratory symptoms and PM ₁₀ in both samples, but strongest for the symptomatic one
Roemer et al., 1993. Two nonindustrial towns in the Netherlands	73 children aged 6-12 with chronic respiratory symptoms	SO ₂ , NO ₂ , PM ₁₀ and black smoke (BS)	Acute respiratory symptoms	Ambient temperature	Follow up Winter 1990-91	Association between PM ₁₀ , BS and SO ₂ with prevalence of wheeze and broncho-dilator use
Romieu et al., 1992. Mexico City	111 preschool children	O ₃	Respiratory related school absenteeism	Demographic data, medical history, sources of indoor air pollution	Follow-up (Three months)	O ₃ exposure associated with elevated risk of respiratory illness
Saldiva et al., 1994. Sao Paulo	Children under five years (excluding neonates)	Daily air pollution (SO ₂ , CO, PM ₁₀ , O ₃ , NO _x)	Daily mortality due to respiratory diseases	Weather, seasonal effects	Ecological, May 1990-April 1991	An association between mortality and the NO _x levels
Schenker et al., 1986. Rural area, Western Pennsylvania	4071 children aged 6-11	SO ₂ measured as 3-hr, 24-hr and annual mean, in low-, moderate and high-pollution areas	Respiratory symptoms and pulmonary function levels	Known predictors	Cross-sectional, Spring of 1979	No significant association for SO ₂ levels (higher exposure slightly above national standards)

Source Study location	Subjects	Exposure ^a	Health outcome ^b	Confounders controlled	Study design ^c period	Association ^d found
Schlipkoter et al., 1986. Two regions in Germany	Children	Two polluted areas, one with substantial emission reduction in the study period	Growth and bone maturation		Cross-sectional surveys. 1974 and 1984	No differences in height between areas and years. Bone age retardation (polluted area) at both surveys
Schmitzberger et al., 1993. European Alpine Region	1626 school age children	SO ₂ , NO ₂ , O ₃ & infrared imaging & lichen mapping in three defined zones of exposure	Pulmonary function (FEV ₁ , FEF ₅₀ , FEF ₇₅) and respiratory status	Age, sex, height, socioeconomic status, passive smoking	Cross-sectional	Decrements of FEV ₁ , FEF ₅₀ and FEF ₇₅ associated with areas of higher SO ₂ , NO ₂ , O ₃ . Higher prevalence of asthma in areas of increased O ₃ .
Schwartz, 1989. USA	Children and youths aged 6-24 years	TSP, NO ₂ , O ₃ , SO ₂	Lung function (FVC, FEV ₁ and peak expiratory flow)	Age, height, race, sex, body, mass, smoking, respiratory symptoms	Cross-sectional	FVC, FEV ₁ and peak expiratory flow showed negative correlations with TSP, NO ₂ and O ₃ .
Schwartz et al., 1991. Five German cities	Children	TSP, NO ₂	Daily counts of children with croup or obstructive bronchitis	Seasonal confounding, weather factors	Follow-up (Two years)	TSP and NO ₂ associated with croup cases. No association with obstructive bronchitis
Spinaci et al., 1985	2385 school children from urban, peripheral urban and suburban areas	SO ₂ , TSP	Respiratory symptoms, pulmonary function	Household pollutants, smoking habits	Cross-sectional	Children from urban areas had lessened pulmonary function and higher prevalence of bronchial secretion with common colds
Stern et al., 1994. Ten Canadian rural communities	School children aged 7-11 years	Moderate and low exposure area of air pollution (sulfates, O ₃)	Respiratory symptoms, pulmonary function	Age, sex, weight, height, parental smoking, gas cooking	Cross-sectional 1985-86	Decrement of FVC and FEV ₁ associated with moderate exposures. No other effects observed.
Ware et al.,	8380 white	TSP, FSO ₄ SO ₂	Respiratory		Follow up	Across the cities:

Source Study location	Subjects	Exposure ^a	Health outcome ^b	Confounders controlled	Study design ^c period	Association ^d found
1986. Six US cities	preadolescent children enrolled between 1974 and 1977		symptoms		one year	frequency of cough associated with mean concentration of all pollutants during follow up Bronchitis and respiratory illness associated with mean particulate concentration
White et al, 1994. Atlanta	Black children aged 1-16 years	O ₃	Asthma or reactive airway disease diagnosed in one public hospital		Ecological June 1990-August 1990	Levels 0.11 ppm associated with high frequency of cases
Wichmann et al., 1989. Germany	8420 children aged 6	Air pollution, traffic pollution (NO ₂ , NO, CO)	Respiratory diseases	Sex, parental education and nationality	Cross-sectional	Croup increased in children with high traffic load Asthma correlated with traffic related pollution

- a SO₂: sulphur dioxide, NO_x nitrogen oxides, NO nitrogen monoxide, NO₂: nitrous dioxide, O₃ ozone, TSP total suspended particulates, PM₁₅, PM₁₀, PM_{2.5}, particulate matter less than 15, 10 and 2.5 microns, FSO₄ sulfate fraction of TSP, CO, carbon monoxide; BS: black smoke.
- b FVC: forced vital capacity; MMEF: maximal mid-expiratory flow rate, V_{max75} flow rate at 75% of expired FVC, FEV₁, forced expiratory volume in 1 second FEV₇₅, FEV₅₀: flow rates at 75 and 50% of vital capacity.
- c Study design inferred, if not given.
- d Major associations given. OR = Odds Ratio

Source: WHO, 1996. Linkage methods for environment and health analysis general guidelines



Environment regulation in India and abroad

In the last several decades, the world motor vehicles production has grown phenomenally. The number of new vehicles produced per year worldwide has risen from about 5 million just after 2nd World War to nearly 55 million in 2001. With GDP and population growth, the world vehicle fleet is likely to rise rapidly.

The resultant growth in vehicle emissions has been a matter of great concern for most countries. The late 60's and early 1970's saw first steps towards controlling vehicular pollution being taken in the US, European Union and Japan. The experiences of these countries are given below.

European union

Air pollution has been one of Europe's main concerns since 1970's. To deal with air pollution problems, the European Union's policy on air quality aims at developing and implementing appropriate instruments to improve air quality. The policy involves controlling emissions from mobile sources, improving fuel quality and promoting and integrating environmental protection requirements into the transport and energy sector. The European Community's environment policy rests on the principles of precaution, prevention, rectifying pollution at source and 'the polluter pays'.

European environmental protection law dates back to a conference of Heads of State or Government in October 1972 that decided a common environmental policy was essential. A number of action programmes provide the framework for this legislation. The European Parliament has been involved with environment policy and is behind a large amount of environment legislations. In 1990, the European Environment Agency and the European environment information and observation network were established with the objectives of providing technical, scientific and economic information and extend help in developing and implementing measures and laws related to environment protection.

The Environment action programmes have initiated EU legislation covering most environmental problems and have achieved positive results regarding some of these - for example reduction of acidification and air pollution and the phasing out of the production of ozone depleting substances. However, serious environmental problems remain in Europe and globally. These include

increasing summer smog in cities, the dispersion into the environment of chemicals, climate change, and bio-diversity losses.

The sixth Environment Action Programme (EAP), "Environment 2010: Our future, Our choice", has emphasised on air pollution as one of the target areas. The objective considered in the Sixth Environment Action Programme is to achieve levels of air quality that do not give rise to unacceptable impacts on, and risks to, human health and the environment. The Community is acting at many levels to reduce exposure to air pollution: through EC legislation, through work at the wider international level in order to reduce cross-border pollution, through working with sectors responsible for air pollution and with national, regional authorities and NGOs, and through research. The focus for the next ten years will be implementation of air quality standards and coherency of all air legislation and related policy initiatives.

In the Sixth Environmental Action Programme (6EAP), reference has been made to the development of a thematic strategy on air pollution under the title "Clean Air for Europe" (CAFÉ). CAFÉ has the general aim of developing a long term, strategic and integrated policy against the effects of air pollution on human health and the environment. This strategy would involve review of implementation of air quality directives and effectiveness of air quality programs in the Member states, improving air quality monitoring and identifying priorities for further actions.

Vehicle emission standards

Initially, emissions regulations in Europe were formulated primarily by the United Nations Economic Commission for Europe (UN-ECE). The ECE was supported by most European nations, including many Eastern European countries. Its role was to produce model standards, which could be adopted by member nations, but it had no power to enforce compliance. Historically, the EC legislative program on vehicle emissions has concentrated on new vehicle standards for a limited range of pollutants (carbon monoxide, hydrocarbons, nitrogen oxides and smoke/particulates).

In its early years, the European Union generally adopted regulations, which were technically identical with the ECE equivalents. This position has changed over time, the European Union has gradually assumed a major role in formulating automotive emissions standards. In the early 1980's, more stringent emission standards were passed first for large cars and then for smaller cars. This process had the effect of requiring catalytic converters on new petrol fuelled cars, and these culminated in the EC directives for Euro I and Euro II standards.

The European Union regulations, published as Directives, have the force of law within EU Member States under the provisions of the Treaty of Rome. With the introduction of the "Consolidated Emissions Directive", implementation has become mandatory for all EU Member States. It is no longer left to the discretion of individual national governments. A four-year transitional period till January 1999 was agreed for the environmental legislation for the countries that had joined recently. After this period, the limits had to be harmonised or renegotiated.

In cooperation with the oil and motor vehicle industry, the Commission devised a common "Auto-oil Program" (AOP) to reduce exhaust gas emissions. This initiative was wide reaching and involved legislators, the European Parliament, academia, consumer groups, the oil industry and the automotive manufacturers. The program started in 1992. Its aim was to set vehicle and fuel standards for the period 2000 - 2010. The Program was very comprehensive and adopted a rational approach to future automotive emissions and air quality legislations. The project was designed to identify the obstacles to achieving the air quality targets and to offer the best cost-effective solutions by the following means:

- Assess vehicle/fuel technology interactions with emissions. Review what was already understood, and then conduct a research programme to fill gaps in the knowledge base.
- Develop a comprehensive emissions inventory.
- Model air quality and compare with possible future standards.
- Build into that model the effects of both currently planned measures and possible future options for legislation.
- Review the cost effectiveness of potential remedial actions.

The European Program on Emissions, Fuels and Engines (EPEFE) set up as a result of the EU Commission's initiative, reviewed available data and designed projects to extend the knowledge base. An appropriate series of programs were carried out, managed by the automotive industry (ACEA) and the European oil industry (EUROPIA). Fuel matrices were designed to study the effect of variations in the sulphur content, mid-range distillation and aromatics content of gasoline and the cetane number, poly-aromatics, density and back-end distillation of diesel fuel. Test vehicles/engines were selected to reflect the wide range of models found in Europe. They were equipped with prototype engine technologies then under development, which improved upon the requirements of the 1995/96 European emissions legislation. In total, EPEFE examined 12 test

gasolines with 16 gasoline vehicles, and 11 diesel fuels in 19 light duty vehicles and 5 heavy-duty engines. More than 2,000 emission tests were run and over half a million data points were generated.

In addition an air quality monitoring exercise was coordinated by the European Commission and was conducted by recognized European experts. It relied on regional and individual base inventories for a number of cities, compiled in 1990. Thereafter accredited emissions forecasting tools were employed to predict future air quality levels. The models had the ability to accommodate detailed breakdowns by both stationary and mobile emission sources and incorporate the effects on emissions of enhanced vehicle technology, modified fuels, non-technical measures such as traffic management and fiscal policies, inspection and maintenance and the use of alternative fuels.

In 1996, the Commission put forward a number of measures and proposals before the Council of European Union and the European Parliament arising from the Auto-oil Program's report. Auto-Oil I led to the adoption of a series of directives regulating emissions of certain pollutants from light-duty vehicles and the quality of petrol and diesel. These were joined subsequently by further proposals concerning emissions from other types of vehicles and improved procedures for inspection and maintenance. This resulted in the setting of Euro 3 and 4 emission limits for passenger cars and light duty vehicles; Euro 3, 4 and 5 emission limits for heavy-duty vehicles; and fuel quality specifications (<http://europa.eu.int/comm/environment/autooil/index.autooil/index.htm> as on September 3, 02). The future emission norms are much more stringent than previous ones. For instance, Euro 4 emission limits for passenger cars (diesel) require around 82% reduction as compared to the Euro 1 standard, in CO and PM pollutants and around 70% reduction in HC + NO_x limits.

In addition to this, under the Kyoto agreement, the European Union has agreed to limit the greenhouse gases. In order to do this, the EU adopted in 1996 a strategy on reducing CO₂ emissions from new passenger cars. As part of this strategy, the Commission has made a voluntary agreement with the European automobile manufacturers, where industry has committed itself to reduce average CO₂ emissions from new passenger cars by 25 % over the next decade, setting a target of 120g/km to be attained by 2005 (2010 at the latest).

The approach broadly followed in AOPII was to identify environmental objectives for air quality; forecast future emissions and air quality; establish emission reduction targets (or appropriate functional relationships); collect input data on costs and effects of potential measures to reduce emissions; and

carry out a cost effectiveness assessment as a basis for a future air quality strategy.

Auto-Oil II involved the estimation of future emissions from road transport and other sources and future air quality and led to a series of conclusions and recommendations on emission reduction measures to be taken in the road transport sector. Auto-Oil II has shown that emissions from road transport of the main regulated pollutants can be expected to fall to less than 20% of their 1995 levels by 2020 although the results for particulate matter cover only diesel emissions. By contrast, CO₂ emissions are expected to continue rising until 2005, before stabilising on the assumption that the voluntary commitments of the car manufacturers are met. These emission reductions are expected in spite of the forecast growth in transport demand.

The results of the recent Auto-Oil II programme¹ have revealed two specific remaining air quality problems, which will need to be major priorities for the next phase of the EU's air quality policy. These relate in particular to particulate matter and ozone.

The details of the EU emission standards for vehicles are elaborated in Annex 3.1.

US

In July of 1970, US Congress adopted the first major Clean Air Act, and established the U.S. Environmental Protection Agency (EPA). It gave the new Agency broad responsibility for regulating motor vehicle pollution. The clean air law called for 90 percent reductions in automotive emissions. The law also directed EPA to set health-based "National Ambient Air Quality Standards" for six pollutants, all of which are present in auto emissions to some degree. These pollutants are called criteria air pollutants because the agency has regulated them by first developing health-based criteria (science-based guidelines) as the basis for setting permissible levels. One set of limits (primary standard) protects health; another set of limits (secondary standard) is intended to prevent environmental and property damage. The criteria pollutants are carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO₂), ozone (O₃), particulate matter (PM), and sulphur dioxide (SO₂). A geographic area that meets or does better than the primary standard is called an attainment area; areas that don't meet the primary standard are called non-attainment areas. EPA and state governors have cooperated to identify non-attainment areas for each criteria air pollutant. Further, EPA has classified the non-attainment areas according to how badly polluted the areas are.

The Clean Air Act is a federal law, which covers the entire country, however, the states do much of the work to carry out the Act. For example, a state air pollution agency holds a hearing on a permit application by a power or chemical plant or fines a company for violating air pollution limits. Under this law, EPA sets limits on how much of a pollutant can be in the air anywhere in the United States. The law allows individual states to have stronger pollution controls, but states are not allowed to have weaker pollution controls than those set for the whole country.

States are required to develop state implementation plans (SIPs) that explain how each state will do its job under the Clean Air Act. A state implementation plan is a collection of the regulations a state will use to clean up polluted areas. The states have to involve the public, through hearings and opportunities to comment, in the development of each state implementation plan. EPA must approve each SIP, and if a SIP isn't acceptable, EPA can take over enforcing the Clean Air Act in that state. The United States government, through EPA, assists the states by providing scientific research, expert studies, engineering designs and money to support clean air programs.

U.S. EPA's Office of Transportation and Air Quality (OTAQ) is responsible for protecting public health and the environment by controlling air pollution from motor vehicles, engines, and the fuels used to operate them, and by encouraging travel choices that minimize emissions. EPA standards dictate how much pollution autos may emit but automakers decide how to achieve the pollution limits.

There have been a variety of approaches and programs that have been adopted by the EPA since 1970's to help control pollution. From better engine design to better transit options, programs to reduce mobile source pollution have attempted to address not only vehicles, engines, and equipment, but also the fuels they use and the people who operate them. Technological advances in vehicle and engine design, together with cleaner, higher-quality fuels, have reduced emissions so much that EPA expects the progress to continue, even as people drive more miles and use more power equipment every year. EPA studies show that today's cars emit 75 to 90 percent less pollution (for each mile driven) than their 1970 counterparts, thanks largely to advancements in vehicle and fuel technology.

The Clean Air Act (1970) required new cars to meet a 0.41 gram of hydrocarbons per mile standard and a 3.4 grams of carbon monoxide per mile standard by 1975; nitrogen oxide emissions were to be reduced to 0.4 grams per mile by 1976 (the nitrogen oxide standard was later revised in 1977). In 1974, the

Energy Policy Conservation Act was adopted by the Congress setting the first fuel economy goals. The Corporate Average Fuel Economy (CAFÉ) program established a phase-in of more stringent fuel economy standards beginning with 1975 model vehicles.

In 1975, "first generation" catalytic converters in 1975 were introduced which significantly reduced hydrocarbon (HC) and carbon monoxide (CO) emissions. Since lead inactivates the catalyst, 1975 saw the widespread introduction of unleaded gasoline. This resulted in dramatic reductions in ambient lead levels and alleviated many serious environmental and human health concerns associated with lead pollution (<http://www.epa.gov/otaq/invtory/overview/solutions/milestones.htm>) as on September 02, 2002).

In 1977, the Clean Air Act was amended at the behest of the automakers. The HC standards were delayed till 1980 and CO and NO_x standards were delayed until 1981. The nitrogen oxides standard was further relaxed to 1 gram per mile. The next major milestone in vehicle emission control technology came in 1980-81. In response to tighter standards, manufacturers equipped new cars with even more sophisticated emission control systems. These systems generally included a "three-way" catalyst (which converts carbon monoxide and hydrocarbons to carbon dioxide and water, and also helped reduce nitrogen oxides to elemental nitrogen and oxygen), plus an on-board computer and oxygen sensor. This equipment helped in optimising the efficiency of the catalytic converter.

In 1983, Inspection and Maintenance (I/M) programs were established in areas where air pollution was a concern. The program required passenger vehicles to undergo periodic testing of the emission control systems. The EPA adopted stringent emission standards for diesel powered trucks and buses to take effect in 1991 and 1994.

Despite considerable progress, the overall goal of clean and healthy air were not met. The level of air pollution was still critical in virtually every major city in the United States. This was largely because development and urban sprawl created new pollution sources and contributed to a doubling of vehicle travel since 1970. Hence it was felt that further emission reductions were essential to further progress toward clean and healthy air for everyone.

With these issues in mind, for the first time since 1977, the Clean Air Act was amended and updated in 1990. The amended Act required further reductions in hydrocarbons, carbon monoxide, nitrogen oxides, and particulate emissions. The amendments also introduced lower tailpipe standards; more stringent

emission testing procedures; expanded I/M programs; new vehicle technologies and clean fuels programs; and transportation management provisions. The tighter tailpipe emission standards began to take effect with 1994 models. A comprehensive approach was taken to reduce the criteria air pollutants by the 1990 Act covering many different sources and a variety of clean-up methods. Many of the smog clean-up requirements involved motor vehicles (cars, trucks, buses). The carbon monoxide (CO) and particulate matter (PM₁₀) clean-up plans were also set up like the plan for smog.

The 1990 law also introduced several entirely new concepts with regard to reducing motor vehicle-related air pollution. For the first time, fuel was considered along with vehicle technology as a potential source of emission reductions. And more attention was focused on reducing the growth in vehicle travel. The act mandated that improved gasoline formulations be sold in some polluted cities to reduce emissions of carbon monoxide or ozone-forming hydrocarbons. Reformulated gasoline (which is designed to reduce emission of volatile organic compounds and toxic air pollutants) was required to be sold in the nine worst areas that did not meet the minimum national air quality standards for ozone. This program began in 1995 in 10 metropolitan areas with severe smog problems. In the areas where wintertime carbon monoxide pollution is significant, refiners are required to sell oxyfuel, gasoline with oxygen added to make the fuel burn more efficiently. Other programs set low vehicle emission standards to stimulate the introduction of even cleaner cars and fuels. The Act also encourages development and sale of alternative fuels such as alcohols, liquefied petroleum gas and natural gas.

The 1990 Clean Air Act provides economic incentives for cleaning up pollution. For instance, gasoline refiners can get credits if they produce cleaner gasoline than required, and they can use those credits when their gasoline doesn't quite meet clean-up requirements.

The various programs that have been introduced are elaborated below (<http://www.epa.gov/otaq/13-fuels.htm>) as on September 2, 2002.

California pilot program

In 1996, the phase in of the pilot program in California started. Under this program, lower hydrocarbon emission standards (relative to cars in the general U.S. market) were set for a set number of new passenger cars and light trucks sold in California beginning in 1996. The standards were to drop still lower beginning in 2001, when a new nitrogen oxide standard also took effect. The sales requirement was 150,000 vehicles per year in 1996 through 1998 and

300,000 vehicles per year thereafter. California was given the option of mandating the availability of any fuel, which was considered necessary to operate clean-fuelled vehicles.

Other states are allowed to adopt California's vehicle standards. Massachusetts, New York, Vermont and Maine have adopted California emission standards beginning in the 1999, 1999, 2000 and 2001 model years, respectively

The California Air Resources Board (ARB) is the state agency responsible for protecting public health and the environment from the harmful effects of air pollution. ARB works in cooperation with the districts and the U.S. Environmental Protection Agency (U.S. EPA) on strategies to attain State and federal ambient air quality standards and reduce air toxics emissions. California's air quality program has achieved substantial progress over the past decades. In the Los Angeles area, the average levels of inhalable particulate matter (PM₁₀) fell by over twenty percent from 1988 to 2000 (<http://www.arb.ca.gov/planning/plan01/draft01.doc>) as on September 02, 2002).

In February 2000, the California ARB adopted a new regulation to reduce emissions of NO_x and PM from urban transit buses. Under this regulation fleet operators have to choose between a "diesel path" and an "alternative fuel path" for their future bus procurements. The alternative fuel path requires that 85% of buses purchased or leased each year through model year 2015 are fueled by alternative fuels. Transit operators who stay on the diesel path can purchase diesel fueled buses, but are required to follow a more aggressive emission reduction schedule. When the regulation is fully implemented, buses on both paths will produce the same near-zero emission levels.

Clean-fuel fleet vehicle program

This provision applies to fleets in 23 metropolitan areas around the country that have high ozone and/or carbon monoxide pollution. This program requires that a certain proportion of the new vehicles sold must meet lower emission standards. A portion of new cars, light trucks, and medium-duty trucks purchased by fleets will need to meet the lower hydrocarbon and nitrogen oxide emission standards beginning in 1998. Individual states must ensure that appropriate fuels are available for clean-fuelled fleet vehicles. It is expected that this program would affect approximately 35,000 fleets and result in about one million clean-fuelled vehicles by 2010. Eighteen areas have opted out of the Clean Fuel Fleet Program while four areas have adopted it.

National low emission vehicles program

In 1998, an agreement was reached between the Clinton administration, the automotive industry and the North-eastern states of the US to put cleaner cars on the road before they could be mandated under the Clean Air Act. The new cars are called National Low Emission Vehicles (NLEV). The NLEVs have been made available across US since 2001.

The National Low Emission Vehicle Program (NLEV) program is a voluntary program to introduce cleaner cars and light trucks in all parts of the country. Under the agreement between the States and automobile manufacturers, manufacturers began selling cleaner model year 1999 and 2000 cars and trucks in a number of districts. Twenty-four of the largest automobile manufacturers have voluntarily entered into the NLEV program. In model year 2001 to 2003 automobile manufacturers will voluntarily sell these cleaner cars and trucks in the 45 states nationwide which are participating in the NLEV program.

Although the automobile manufacturers volunteered for the program, the lower emission levels and other requirements of the NLEV program are enforceable like any other federal new vehicle program. The NLEV program will continue to exist until the cleaner Federal emission standards become effective in the 2004 model year.

The National LEV program harmonizes the federal and California motor vehicle standards. The program is phased-in through schedules that require car manufacturers to certify a percentage of their vehicle fleets to increasingly cleaner standards.

Vehicle exhaust emission standards

For cars and light duty vehicles, two sets of standards, Tier 1 and 2, have been defined in the Clean Air Act. The Tier 1 regulations were fully implemented in 1997. The Tier 2 standards were adopted on December 21, 1999, to be phased-in beginning in 2004. The Tier 2 standards bring significant emission reductions relative to the Tier 1 regulation. Under the Tier 2 standard, the same emission standards apply to all vehicle weight categories under cars and light duty vehicles. Further, the emission limits that apply to all vehicles are fuel neutral. That is, vehicles fueled by gasoline, diesel, or alternative fuels all must meet the same standards. In case of heavy-duty vehicles, emission standards for NO_x and PM have become very stringent over time. For instance, the emission standards for model year 2007 are 0.01 g/bhp-hr and 0.2 g/bhp-hr for PM and NO_x

respectively, a reduction of around 97-98% over the 1990 emission standards.

The details of the vehicle emission standards are given in Annex 3.2.

Japan

In Japan, the maximum permissible limits on the amount of exhaust gases from motor vehicles are established by the Directorate General of the Environment Agency (EA) as prescribed by the Air Pollution Control Law (1968) and are adopted by the Ministry of Transport (MOT). In addition, EA also establishes the maximum permissible limits on the quality of automobile fuel and on the quantity of substances in automobile fuel, which are necessary to prevent air pollution caused by automobile exhaust gases. The MOT sets the emission targets on reduction rates based on recommendations by the Central Council for Environmental Pollution Control (CCEPC), an advisory body of the Ministry of Environment.

Emission control in Japan started in 1966 when simple CO limits were introduced for ordinary-sized and small-sized motor vehicles fuelled by gasoline, but the first long-term plan was established in 1970 by the Ministry of Transport (MOT). This plan proposed limits for CO, HC and NO_x from 1973. In 1971, the Central Council for Environmental Pollution Control (CCEPC), recommended that legislation should follow the US "Muskie proposal" and submitted recommendations for much more stringent exhaust emission standards. This led to tough limits introduced in 1975, which required the use of catalysts on gasoline cars. These limits (with an NO_x reductions in 1978) have not changed since then, but revisions to the test procedures have effectively made them more severe. Emissions limits for trucks, both gasoline and diesel were also introduced in 1974/5, but these limits have been tightened by varying degrees over the intervening years.

At present, carbon monoxide, hydrocarbons and nitrogen oxides are regulated for motor vehicles fuelled by gasoline or LPG (gasoline/LPG motor vehicles). In case of diesel-powered motor vehicles, in addition to these three, particulate matter, and diesel smoke among particulate matters, are also regulated.

In December 1989 the CCEPC recommended new emission limits with both short-term (relating to diesel motor vehicles and fuel evaporative emission reduction for the gasoline motor vehicles) and long-term targets (relating to LPG motor vehicles, off-road vehicles and two-wheeled motor vehicles) (<http://www.env.go.jp/en/pol/mv/policy.html>) as on September 5, 02). Their aim was to set up the most stringent standards, which were technologically

feasible, and to apply the same standards for both gasoline and diesel fuelled vehicles in the near future. All of these measures were scheduled to be implemented by the year 1999. Based on this proposal the MOT revised the emission regulations in May 1991 to incorporate the short-term limits. The major changes were as follows:

- Reductions in NO_x emissions from commercial vehicles.
- Introduction of particulate standards and more stringent smoke limits for diesel vehicles. Smoke limits were reduced by 20% in 1993 for light and medium duty diesel vehicles. Heavy duty and passenger vehicle limits were to follow suit in 1994.
- Revision of test cycles and measurement modes.

In 1991, the EA set up a committee to consider the introduction of limits for motorcycles and “special” vehicles (e.g. off road).

A joint study conducted by MOT/MITI/EA proposed legislation to further reduce NO_x in urban areas. These proposals were adopted in December 1992, to take effect December 1993. The objective was to control both the population of older vehicles and impose even tougher emission limits for new vehicles. It was proposed that the regulations would apply to all diesel vehicles in the specified areas. However, there were a number of derogations for various classes of older vehicles. In 1992, the Law Concerning Special Measures for Total Emission Reduction of Nitrogen Oxides from Automobiles (Automobile NO_x Law) was passed. With regard to specific areas in which such pollution is most severe, the law sets forth the fundamental policies and plans for reducing the total volume of automobile emitted nitrogen oxide, establishes nitrogen oxides emission standards for specific automobiles which are registered in those areas, and employs necessary measures for restricting the amount of nitrogen oxides emissions resulting from use of automobiles for business activities.

In 1996 the MOT announced its plans to implement more of the proposals of the Central Council for Environmental Pollution Control suggested in December 1989. A report on the “Future Policy for Motor Vehicle Exhaust Emission Reduction” was submitted in 1996. Based on this Report, the following measures listed below were scheduled to be enforced in the years of 1998 or 1999.

1. Emission reduction of hydrocarbons, etc. through introduction of an exhaust emission control standard for two-wheeled motor vehicles,
2. Emission reduction of hydrocarbons, etc. through strengthened exhaust emission control standards for gasoline/LPG motor vehicles, and

3. Employment of low-benzene gasoline by means of the automotive fuel quality regulations

In June 2001, Japan's legislature, the Diet enacted a law designed to further tighten controls on NO₂ and PM emissions from diesel powered vehicles in order to improve air quality in major urban areas. The law applies to a total of 196 city, ward, town and village governments in Tokyo, Saitama, Chiba, Kanagawa, Hyogo and Osaka (<http://environment.about.com/library/weekly/blairpol1.htm>) as on September 5, 02).

In April 2002, the Central Environment Council finalized its fifth report of deliberations on "Future Policy for Motor Vehicle Exhaust Emission Reduction". The report's recommendations include (1) new long-term targets for emissions from diesel motor vehicles, which will be effective from 2005, (2) new long-term targets for emissions from gasoline motor vehicles and deadlines for achieving them, (3) a revision of test modes, (4) a reduction of sulphur in gasoline, and other items. The Ministry of the Environment plans to strengthen regulations based on this report.

The new regulation calls for reducing PM emissions from trucks and buses by up to 85 percent and NO_x emissions by 50 percent from the levels set in the short-term diesel auto emission regulation that is scheduled to be enforced between fiscal 2002 (starting April 1) and fiscal 2004 (ending March 2005). The MOE also is preparing to enforce a tougher regulation on hydrocarbons, NO_x, and SO_x emitted from gasoline-powered vehicles-so-called Ultra-Low Emission Vehicles (ULEVs). The new regulation toughens the short-term emission regulation that will be in effect between April 1, 2002, and March 31, 2005 (fiscal 2002-2004).

The new emissions level would be cut to 0.027 gram per kilowatt per hour for PM from 0.18 gram per kWh under the 2002-2004 regulation, or an 85 percent reduction. The standards for NO_x emissions for the same category of trucks must be cut to 2 grams per kWh from 3.38 grams under the 2002-2004.

For gasoline-powered passenger vehicles weighing more than 1.25 tons, the new standards for PM must be less than 0.014 gram per kilowatt-hour compared with 0.056 gram per kWh under the 2002-2004 regulation, and NO_x must be less than 0.15 gram per kWh from 0.3 gram under the 2002-2004 regulation. The Japanese New-Long-Term Regulations, decided on March 5 2002, will start from October 2005.

The details of the vehicle exhaust emission standards in Japan are given in Annex 3.3.

Developing countries

Many of the developing countries are also facing significant vehicular pollution problems. Their Governments are actively working towards controlling pollution from the transport sector. Several countries like Argentina, Brazil, Thailand, China, Mexico, Nepal etc have adopted vehicular emission standards based on the European emission regulations.

Nepal

In Nepal, air pollution problem has become critical over the years. The main problem is high concentration of particulate matter in the air, Total Suspended Particles and PM10 concentrations are significantly higher than the WHO guidelines. The Government of Nepal first responded by stopping the import of three wheelers into the valley in 1991 November. In 1995, the Ministry of Population and Environment (MoPE) was established to deal with environmental issues.

Ministry of Labour and Transport Management, Ministry of Works and Physical Planning, Ministry of Population and Environment, and Ministry of Finance are the central level government ministries primarily responsible for making decisions on the development of transport sector in an environment friendly manner. Department of Transport Management is the main implementing agency of transport policy. The various preventive and corrective measures that have been adopted by the Government are listed below (<http://www.cen.org.np/publications.htm#> Fact Sheets as on September 24 02):

- Import of only unleaded gasoline and less than 0.25% sulphur content diesel
- Ban on the import of two stroke engine vehicles, second hand and reconditioned vehicles
- Introduction of vehicle emission standards for existing vehicles plying in the streets (4.5% and 3% CO for petrol four wheelers manufactured upto 1980 and 1981 onwards respectively; 75 HSU and 65 HSU for diesel vehicles upto 1994 and 1995 onwards respectively).
- Introduction of Nepal Vehicle Mass Emission Standard 2056 (based on EURO-I emission standards) for new vehicles to be imported and banning entry of vehicles older than 5 years

- Phasing out of highly polluting diesel operated three wheelers from Kathmandu Valley
- Ban on all public vehicles older than 20 years (this regulation was to be effective from November 2001 onwards, however, it has not yet been implemented)

MoPE also initiated a program of testing vehicle emissions. Almost all vehicles, except two-wheelers plying in the valley have undergone the testing process.

The Nepalese Government recently introduced a new transport policy- National Transport Policy 2001. The integration of the environmental consideration in the transport management field is one of the major highlights of this policy. This policy gives highest priority for the promotion of electric vehicles. The proper maintenance of roads, equalization of traffic density within the capacity of roads, preference for mass transport, compliance to environmental requirements, and running of public transport purely on competitive basis are some other highlights of this policy.

Current and pending environment regulations in India

There has been a tremendous growth in the vehicle population of India with the total population today being around 40 million. While the growth of the transport sector is essential for efficiency of the economy, the adverse effect of has been that the Indian transport sector has come to be a major contributor to the emission loading. According to the World Health Organization, the capital city of New Delhi is one of the top ten most polluted cities in the world.

History of emission norms in India

The Indian Government has formulated a number of regulations, policies and programs for protecting the environment. Some of these relating to air pollution are Air (Prevention and control of pollution) Act of 1981, the Environment (Protection) Act of 1986, and the Policy Statement on Abatement of Pollution, 1992. Under the former Act, Central and State Boards for Prevention and Control of Air Pollution were constituted. Their functions included planning a comprehensive programme for the prevention, control or abatement of air pollution and to secure its execution (<http://envfor.nic.in/legis/legis.html> as on August 29, 20). As per the Environment Act, the Central Government, has the power to take all measures it considers necessary or expedient for the purpose of

protecting and improving the quality of the environment and preventing controlling and abating environmental pollution.

The Policy Statement on Abatement of Pollution, 1992 states the government's commitment to prevent further deterioration of the environment. The policy sought to shift the emphasis from defining the objective for each problem area towards actual implementation with long-term focus and making maximum use of mix of instrument including legislative and regularisation, fiscal incentive, voluntary agreement, education programme and information campaign to achieve these objectives.

Laws to control vehicular pollution need periodic revisions of emissions regulations dealing with vehicles and fuel quality. The Motor Vehicle Act of 1939 was amended in 1988 to regulate vehicular emission. The Motor Vehicles Act and the Central Motor Vehicles rules (CMVR) are the principal instruments for regulation of motor vehicular traffic through out the country. The implementation of various provisions of this Act rests with the State Governments. The Ministry of Road Transport and Highways (MoRT&H) acts as a nodal agency for the formulation and implementation of various provisions of the Motor Vehicle Act and CMVR. The Ministry of Road Transport & Highways is advised by CMVR- Technical Standing Committee on various technical aspects related to CMVR. This Committee has representatives from various organisations namely; Ministry of Heavy Industries (MoHI), Ministry of Road Transport & Highways (MoRT&H), Bureau Indian Standards (BIS), Testing Agencies such as Automotive Research of India (ARAI), Vehicle Research Development & Establishment (VRDE), Central Institute of Road Transport (CIRT) and industry representatives from Society of Indian Automobile Manufacturers (SIAM) & Automotive Component Manufacturers Association (ACMA).

Although Air Act, 1981 and Environment (Protection) Act, 1986 provide for the prescription of Automobile emission standards by CPCB or Ministry of Environment & Forests, implementation and enforcement of these standards is the responsibility of the Union Ministry of Road Transport and Highways or the Transport Commissioner at the state level. For the issues related to implementation of emission regulation the MoRT&H is advised by a separate Committee namely Standing Committee on Implementation on Emission Legislation. MoRT&H has formulated this committee to discuss the future emission norms, the related test procedures and the implementation strategy, in consultation with all stakeholders.

The initial active steps towards controlling vehicular pollution were taken by the Supreme Court of India in response to a writ petition files in 1985. Judicial activism is responsible to a large extent for the substantial progress that has been made in several issues relating to reducing of vehicular pollution. Also environment regulation in the transport sector of the country has been largely through command and control measures rather than fiscal incentives. Greater emphasis has been laid on setting standards and promoting specific technologies by mandating their usage.

The general consensus in India was to follow the European emission norms. The formal specification of emission standards for vehicles began only in 1991. In 1991, the first stage of emission norms came into force for petrol vehicles and in 1992 for diesel vehicles. In 1996, there was a further tightening of auto emission norms and fuel quality specifications. Thereafter, the MoRT&H in consultation with the Ministry of Environment and Forest has made the emission standards progressively stricter for different categories of vehicles, thereby narrowing the gap between the standards applicable in the developed world and in India. From April 1995 mandatory fitment of catalytic converters in new petrol passenger cars sold in the four metros of Delhi, Calcutta, Mumbai and Chennai along with supply of Unleaded Petrol (ULP) was effected and later extended to 45 cities of the country. From 2000 onwards, ULP was made available across the country. Bharat Stage I norms (equivalent to Euro-I norms) were brought into force with effect from 1.04.2000 throughout the country for all categories of vehicles. Bharat Stage-II norms, which are akin to Euro-II norms have been introduced in National Capital Region (NCR) for passenger vehicles upto GVW 3.5T from 1.4.2000 and for heavier vehicles from 24.10.2001 in National Capital Territory (NCT) of Delhi. In case of Mumbai, these have been extended from 1.1.2001 and 31.10.2001 respectively. For both Chennai and Kolkata, the corresponding dates are 1.7.2001 and 31.10.2001 respectively. Fitness norms for commercial vehicles have been tightened with effect from 28th March, 2001 (<http://www.morth.nic.in/emission.htm> as on August 27, 02). The emission norms for CNG and LPG vehicles were notified in the year 2000 and 2001 respectively.

The Central Motor Vehicles Rules have been frequently amended to take into account the changing requirements. The amendments already notified include tightening of fitness norms in respect of transport vehicles; increasing the fees for issue of driving licenses; introduction of high security registration plate; change in colour scheme for registration plates; introduction of certain safety related features; introduction of Bharat Stage-II norms in respect of heavy

vehicles to the four major Metros, the norms and rules for use of Liquefied Petroleum Gas, etc.

The emission norms in India are behind the European ones's by four to five years for all categories of vehicles except for two and three wheelers. In case of these, Bharat 2000 norms are far stricter than the Euro II norms and are one of the most stringent in the world. The details of the emission norms are given in Annex 3.4.

Fuel technology

The vehicle technology and fuel system should be treated as an integrated whole. However, this has not been the case in India. The initiative for improving fuel quality was taken by the Supreme Court beginning with the phasing out of lead in petrol in the four metropolitan cities of the country (Delhi, Mumbai, Chennai and Kolkata) in 1994. The Ministry of Environment and Forests notified fuel specifications in 1996.

Since April 2000 unleaded petrol with a sulphur content of 0.1% is available in the entire country. In the metropolitan cities the sulphur content in petrol has been further reduced to 0.05%. A similar program to reduce sulphur content in diesel was effected in 1996. At present the sulphur content in diesel available across the country has been reduced to 0.25%. In case of the four metropolitan cities, the sulphur content has been further reduced to 0.05%. The details of these programs are given in the tables below.

Table 3.1 Phase-out programmes for lead in gasoline

Phase I	June 1994	Low leaded (0.15 g/litre)	Cities of Delhi, Mumbai, Calcutta and Chennai
Phase II	April 1995	Unleaded (0.013 g/ litre) (+ low leaded)	Cities of Delhi, Mumbai, Calcutta and Chennai
Phase III	January 1997	Low leaded (0.15 g/ litre)	Entire country
Phase IV	September 98	Ban on Leaded fuel (only unleaded fuel)	NCT Delhi
Phase V	September 98	Unleaded (0.013 g/ litre) (+ low leaded)	All other capitals of State/Union territories and other major cities.
Phase VI	January 99	Unleaded only (0.013 g/ litre)	NCR
Phase VII	April 2000	Unleaded only (0.013 g/ litre)	Entire country

Source: TEDDY, 2001

Table 3.2 Phase-out programme for sulphur in diesel

Phase I	April 96	Low sulphur (0.5%)	Four metros and Taj Trapezium
Phase II	August 97	Low sulphur (0.25%)	Delhi and Taj Trapezium
Phase III	April 98	Low sulphur (0.25%)	Metro cities
Phase IV	April 99	Low sulphur (0.25%)	Entire country
Phase V	April 2000	Low sulphur (0.05%)	NCR; Mumbai, Chennai and Kolkatta (in 2001)

Source: TEDDY, 2001

The maximum limits for critical ingredients like Benzene in petrol have been specified only recently and a limit of 5% m/m and 3% m/m has been set for petrol in the country and metros respectively. The benzene content in petrol has been further reduced to 1% in Delhi and Mumbai.

In addition to petrol and diesel, CNG and LPG are permitted to be used as auto fuels. In a number of cities of India like Delhi, Mumbai, Surat etc CNG is quite popular. In fact in Delhi, as per the directives of the Supreme Court, the entire bus fleet and intermediate public transport (Autorickshaws and taxis) are being steadily converted to CNG. Auto LPG is being promoted in the major cities of the country by a number of oil companies. Alternative fuels like di-methyl ether, bio-diesel, hydrogen, electric and fuel cell vehicles etc., are at various stages of experimentation.

Phasing out of vehicles

There is no specification of age limit of vehicles at the national level. However, in some of the metropolitan cities like Delhi and Mumbai, age limits have been specified. In Delhi, as per the specification of the Supreme Court, commercial vehicles more than 15 years old have been phased out with effect from December 1998. Buses that are 8 years or more have also been phased out. The replacement of pre-1990 and conversion of post-1990 autorickshaws and taxis to clean fuels is in progress in the capital. In Mumbai, three cylinder diesel engine taxis are being phased out. However, as far as private vehicles are concerned no such age limit has been imposed.

Inspection and maintenance of in-use vehicles

In India currently as prescribed by the Central Motor Vehicles Rules, only transport vehicles, that is, vehicles used for hire are required to undergo periodic fitness certification. The large population of personalised vehicles are not yet covered by any such mandatory requirement. The Supreme Court in its 1997-98 order required immediate setting up of automated inspection and maintenance facilities for the commercial vehicles in the first phase and comprehensive I&M programs to be started by the Transport department and private sector.

Recommendation of various committees

White paper by MoEF

In view of the rapidly growing environmental pollution in the national capital, the MoEF came out with a white paper on pollution in Delhi with an Action plan (<http://envfor.nic.in/divisions/cpoll/delpolln.html> as on September 5, 02). The white paper covered various aspects of pollution control, including vehicular and industrial pollution, solid waste management and noise pollution. The proposals and the action plans were concurred on 8 August 1997. The measure for controlling vehicular pollution included improved traffic management, strengthening of public transportation to reduce congestion and the use of personal vehicles, improvement in the quality of fuel, decongestion of Delhi through the relocation of whole sale markets, and better land use planning. In the paper, emissions from each category of vehicles were routinely identified. However, there was no focussed approach or cohesive strategy for their implementation.

Other Directives by Supreme Court

Some of the other important directives given by the Supreme Court (<http://www.iglonline.net/legal.asp> and <http://www.teriin.org/urban/court.htm> as on September 2, 02) are listed below:

1. The Court directed that the entire city bus fleet of the capital be steadily converted to a single fuel CNG, by March 2001. The date was extended to 31 January, 2002. Recently, on April 5 2002, the Supreme Court imposed Rs 500 fine effective from 1st February 2002 and Rs 1000 effective from April 6 2002, on diesel buses, which continued to ply on the roads against the Court's orders. The apex court also directed that priority should be given for supply of CNG to transport sector all over the

country. The Court also gave order for the augmentation of public transport (stage carriage) to 10,000 buses by March 2001.

2. Measures to check fuel adulteration: the Court directed that two independent fuel testing laboratories be established. One such independent laboratory has been commissioned at NOIDA.

EPCA committee report

The Supreme Court vide its order in March 2001 directed that a report be submitted on clean fuels indicating which fuels can be regarded as clean, non-polluting and not injurious to health. The Environment Pollution Authority for the National Capital Region in its report to the Supreme Court on clean fuels reported that only non-hydrocarbon fuels such as electricity, solar energy and fuel cells do not emit noxious pollutants (EPCA, 2001). However, these fuels are not yet commercially available for automobiles. The hydrocarbon fuels which are available and which can be regarded as 'environmentally acceptable fuels' under the prevailing pollution levels and available emission control technologies include CNG, LPG and propane. It further stated that Ultra Low Sulphur Diesel (ULSD with a maximum sulphur content of 10-30 ppm) and petrol (without lead and reduced benzene level) could be considered environmentally acceptable provided that they were unadulterated and used in combination with after-treatment devices such as particulate traps and catalytic converters. 500 ppm S diesel, which is compatible with Bharat Stage II emission norms cannot be regarded as environmentally acceptable and must be treated as a transition fuel permitted for a limited period. Similarly, in case of petrol, though phasing out of lead and reduction of benzene have considerably improved the quality of fuel, it cannot be called an environmentally acceptable fuel. It would be necessary to use catalytic converters for treatment of exhaust gases, assure non-adulteration and further reduce polluting constituents such as sulphur, aromatics and olefins. The report suggested that all environmentally acceptable fuels should be promoted by the Government. Also, the Government should make plans for improving the quality of other fuels with relevant exhaust treatment devices and engine technology so that different options can compete in the market.

Mashelkar committee report

On 13th September 2001, the Government of India constituted a committee of experts of national repute, headed by Dr R A Mashelkar, Director General, Council of Scientific and Industrial Research to recommend an "Auto Fuel Policy" for the major cities of the country, to devise a road map for its

implementation and recommend suitable auto fuels, automobile technologies and fiscal and institutional measures (Auto Fuel Policy, 2001). The Committee presented its interim report in January 2002 which the government accepted the report.

The committee came out with its final report in August 2002. It has recommended that Bharat Stage II norms for all vehicles except for 2 and 3 wheelers across the entire country would become effective from April 2005 and Euro III from April 2010. For the megacities, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur and Agra the recommendation is for Euro II emission norms to become effective from April 2003. Euro III equivalent emission norms for all private vehicles, the city public transport vehicles and city commercial vehicles in the above mentioned cities and the four metropolitan cities (Delhi, Mumbai, Kolkata and Chennai) would be applied with effect from April 2005. The committee has recommended that Euro IV norms should be implemented from the year 2010 in major cities (mentioned above) of the country. For 2 and 3 wheelers, recommendations are for Bharat stage II norms to be effective across the entire country from April 2005 and Bharat stage III norms to be effective preferably from April 2008 but not later than April 2010.

The committee has also laid down a road map for in-use/old vehicles. For the National Capital Territory of Delhi, the committee has recommended that the new PUC checking system and Inspection & Maintenance system should be put in place by October 2003 and April 2005 respectively. The emission norms for city buses, taxis & 3 wheelers should be as per the Supreme Court order. The inter-state buses from/to Delhi and the inter-state trucks loading/unloading goods from/to Delhi should conform to minimum Bharat Stage I norms by April 2004 and Bharat Stage II norms by April 2008. For the cities of Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur and Agra, it has suggested that city buses and taxis should conform to at least 1996 emission norms by April 2004. These vehicles, which are registered before the introduction of Bharat Stage II norms should have minimum Bharat Stage I emission norms by April 2008. For 3 wheelers (autos/tempo) in these cities, those registered before April 2000 should have minimum 1996 emission norms from April 2004 onwards and by April 2008 they should have minimum Bharat Stage I norms. For inter-state buses registered before April 2000 in these mega cities, they should conform to at least 1996 emission norms from April 2004 onwards. The inter-state buses registered after April 2000 should have minimum Bharat Stage I norms by April 2004. Those registered after April 2005

should conform to minimum Bharat stage II emission norms by April 2008. The new PUC checking system and Inspection and Maintenance system for all categories of vehicles should be put in place by April 2004 and April 2006 respectively. The finalisation of plans of augmentation of city public transport system by the state Government/ local authorities should be done not later than April 2006.

V M Lal Committee Report for Mumbai

In Mumbai, a Writ Petition was filed in 1999 in public interest by the Smoke Affected Residents Forum seeking appropriate directions from the High Court with a view to controlling and reducing vehicular emissions in the city. Some leading doctors and cardiologists of Mumbai had averred that up to 40% of the inhabitants suffer from respiratory diseases and illnesses such as asthma, bronchitis, etc. According to some studies, the children in Mumbai have marked stunted development of lungs when compared to children in Madras.

The Mumbai High Court also constituted a committee under V M Lal, then Transport commissioner under an order dated 15 December 1999

(http://www.mahatransport.org/vm_lal/chapters.htm as on August 26, 02).

The committee has given several recommendations on the improvement in fuel quality, use of alternative fuels such CNG/reformulated gasoline, desirability and feasibility of converting the existing buses/taxis to CNG, assessment of the existing emission norms, applicability of EURO I and II norms to commercial vehicles, phasing out vehicles, improvement of emission levels of in-use vehicles and prevention of fuel adulteration, etc. These recommendations have been placed before the High Court and are under various stages of consideration/implementation.

Issues for consideration

In past few years major steps have been taken by both developed and developing countries to control vehicles emissions. Substantial emission reductions have been achieved by vehicular pollution abatement programs in several countries. Hence there is a potential for improvement in case of recently started programs in other countries. Some of the issues, which would be relevant in the future emission reduction programs, are listed below.

- Vehicles are manufactured globally by a limited number of companies, which operate not only in the developed countries but also in developing countries. These companies are producing vehicles conforming to varying degrees of stringency of emission norms depending upon the respective jurisdictions.

Hence, lack of availability of advanced technology is not likely to pose any problems in the introduction of more stringent emission norms in India.

Also several developing countries (relevant for India in terms of export markets) appear to be on track to reach world-class emission standards within the next decade. Hence, both the domestic and foreign markets are likely to move towards more stringent emission regulations.

- Vehicle technologies and fuel properties are very closely intertwined. This has become increasingly clear as emission regulations have become more stringent. Certain fuel parameters like lead or sulphur content would be (and have been in the past) controlled as a precondition to introducing advanced vehicle technologies. Hence vehicles and fuels would have to be treated as a system.
- Vehicles operating on different fuels frequently compete for the same market. In the past, governments have often set different standards for different fuels, thereby introducing distortions into the marketplace and undercutting the goals of clean air. For instance, if both petrol and diesel cars compete for the same market and the latter has a more lenient NOx standard, then this would give it a competitive advantage stimulating its sales. Hence future emission standards for vehicle are expected to be fuel neutral. The emission limits for light duty vehicles in US under the Tier 2 program are going to be fuel neutral.
- Inspection and Maintenance programs should be used to control lifetime in-use vehicle emissions. Given the fact that today's vehicles rely on proper functioning of emission control devices to keep pollution levels low, a minor malfunction in this system can boost emissions significantly. Hence well managed I & M programs are key to controlling in-use emissions. The existing PUC system in India is not effective and adequate. Hence, it is expected that I & M programs are made mandatory and more effective requiring active participation of the vehicle manufacturers.
- Manufacturers should start thinking about equipments such as Onboard Diagnostics (OBD) that identify failure modes and store failure data should be required for all new vehicles. These computers are capable of identifying problems that result in high emissions.

Annex 3.1 Emission standards in EU

Light duty vehicles

Light duty vehicles (passenger cars) were the first to be regulated under the ECE process. Their limit values have been subsequently been amended. The EU light duty vehicle standards are different for diesel and petrol vehicles. Diesels have lower CO standards but are allowed higher NO_x. Gasoline vehicles are exempted from PM standards. The 2000/2005 standards were accompanied by an introduction of more stringent fuel quality rules that require minimum diesel cetane number of 51 (year 2000), maximum diesel sulphur content of 350 ppm in 2000 and 50 ppm in 2005, and maximum petrol (gasoline) sulphur content of 150 ppm in 2000 and 50 ppm in 2005. Light commercial vehicles have been further classified according to their mass, to reflect the differences in their power train layouts and body shapes.

The standards for new cars light trucks are summarized in Tables 3.3 and 3.4.

Table 3.3 EU Emission Standards for Passenger Cars, g/km

Tier	Year/Month	CO	HC	HC+No _x	No _x	PM
Diesel						
Euro I	1992	2.72	-	0.97	-	0.14
Euro 2 - IDI	1996	1.0	-	0.7	-	0.08
Euro 2 - DI	1999	1.0	-	0.9	-	0.10
Euro 3	2000.01	0.64	-	0.56	0.50	0.05
Euro 4	2005.01	0.05	-	0.30	0.25	0.025
Petrol (Gasoline)						
Euro 3	2000.01	2.30	0.20	-	0.15	-
Euro 4	2005.01	1.0	0.10	-	0.08	-

DI – Direct injection

IDI – Indirect injection

Source <http://www.dieselnet.com/standards/eu/ld.html> as on September 3, 2002

Table 3.4 EU Emission Standards for Light Commercial Vehicles, g/km

Class	Tier	Year	CO	HC	HC+Nox	Nox	P.M.
Diesel							
N1 <1305 kg	Euro 1	1994.10	2.72	-	0.97	-	0.14
	Euro 2	1998.01	1.0	-	0.60	-	0.10
	Euro 3	2000.01	0.64	-	0.56	0.50	0.05
	Euro 4	2005.01	0.50	-	0.30	0.25	0.025
N2 1305-1760 kg	Euro 1	1994.10	5.17	-	1.40	-	0.19
	Euro 2	1998.01	1.2	-	1.1	-	0.15
	Euro 3	2002.01	0.80	-	0.72	0.65	0.07
	Euro 4	2006.01	0.63	-	0.39	0.33	0.04
N3 >1760 kg	Euro 1	1994.10	6.90	-	1.70	-	0.25
	Euro 2	1998.01	1.35	-	1.3	-	0.20
	Euro 3	2002.01	0.95	-	0.86	0.78	0.10
	Euro 4	2006.01	0.74	-	0.46	0.39	0.06
Petrol (Gasoline)							
N1 <1305 kg	Euro 1	1994.10	2.72	-	0.97	-	-
	Euro 2	1998.01	2.2	-	0.50	-	-
	Euro 3	2000.01	2.3	0.20	-	0.15	-
	Euro 4	2005.01	1.0	0.1	-	0.08	-
N2 1305-1760 kg	Euro 1	1994.10	5.17	-	1.40	-	-
	Euro 2	1998.01	4.0	-	0.65	-	-
	Euro 3	2002.01	4.17	0.25	-	0.18	-
	Euro 4	2006.01	1.81	0.13	-	0.10	-
N3 >1760 kg	Euro 1	1994.10	6.90	-	1.70	-	-
	Euro 2	1998.01	5.0	-	0.80	-	-
	Euro 3	2002.01	5.22	0.29	-	0.21	-
	Euro 4	2006.01	2.27	0.16	-	0.11	-

N1, N2 and N3 are weight classes for the vehicles.

Source <http://www.dieselnet.com/standards/eu/ld.html> as on September 3, 2002

The useful vehicle life for the purpose of emission regulations is 80,000 km through the Euro 3 stage, and 100,000 km beginning at the Euro 4 stage (2005). The 2000/2005 regulations include several additional provisions, such as:

- EU Member States may introduce tax incentives for early introduction of 2005 compliant vehicles.
- Requirement for on-board emission diagnostics systems (OBD) phased-in between 2000 and 2005.
- Requirement for low temperature emission test (7°C) for gasoline vehicles effective 2002.

Heavy-duty vehicles

For new heavy-duty diesel engines, the environment regulations are specified till Euro V. The Euro II regulations, which came to power in 1996, applied to both heavy-duty highway diesel engines and urban buses. The urban bus standards however were voluntary. In 1999, the European Parliament and the Council of Environment Ministers adopted the final Euro III standard and also adopted Euro IV and V standards for the year 2005/2008. The standards also set specific, stricter values for extra low emission vehicles (also known as "enhanced environmentally friendly vehicles" or EEVs) in view of their contribution to reducing atmospheric pollution in cities. The details of the emission standards for diesel and gas engines and heavy-duty diesel engines are given in Tables 3.5 and 3.6 respectively.

It is expected that the emission limit values set for 2005 and 2008 will require all new diesel-powered heavy duty vehicles to be fitted with exhaust gas after-treatment devices, such as particulate traps and DeNOx catalysts. The 2008 NOx standard will be reviewed by December 31, 2002 and either confirmed or modified, depending on the available emission control technology. Changes in the engine test cycles have been introduced in the Euro III standard (year 2000). The old steady state engine test cycle ECE R-49 will be replaced by two cycles: a stationary cycle ESC (European Stationary Cycle) and a transient cycle ETC (European Transient Cycle). Smoke opacity is measured on the ELR (European Load Response) test.

For the type approval of new vehicles with diesel engines according to the Euro III standard (year 2000), manufacturers have the choice between either of these tests. For type approval according to the Euro IV (year 2005) limit values and for EEVs, the emissions have to be determined on both the ETC and the ESC/ELR tests. Emission standards for diesel engines that are tested on the ETC

test cycle, as well as for heavy-duty gas engines, are summarized in Tables 3.5 and 3.6.

Table 3.5 Emission Standards for Diesel and Gas Engines, ETC Test, g/kWh

Tier	Year/Month & Category	Test Cycle	CO	NMHC	CH ₄ ^a	NO _x	PM ^b
Euro III	1999.10, EEVs only	ETC	3.0	0.40	0.65	2.0	0.02
	2000.10	ETC	5.45	0.78	1.6	5.0	0.16 0.21 ^c
Euro IV	2005.10		4.0	0.55	1.1	3.5	0.03
Euro V	2008.10		4.0	0.55	1.1	2.0	0.03

a - for natural gas engines only

b - not applicable for gas fuelled engines at the year 2000 and 2005 stages

c - for engines of less than 0.75 dm³ swept volume per cylinder and a rated power speed of more than 3000 min⁻¹

EEV – Enhanced environmentally friendly vehicle; ESC – European Stationary Cycle; ETC – European Transient Cycle; ELR – European Load Response test; ECE R-49 - steady-state diesel engine test cycle introduced by ECE Regulation No.49.

Source <http://www.dieselnet.com/standards/eu/hd.html> as on September 3, 2002

Table 3.6 EU Emission Standards for HD Diesel Engines, g/kWh (smoke in m⁻¹)

Tier	Year/Month & Category	Test Cycle	CO	HC	NO _x	PM	Smoke
Euro I	1992, <85 kW	ECER-49	4.5	1.1	8.0	0.612	
	1992, >85 kW		4.5	1.1	8.0	0.36	
Euro II	1996.10		4.0	1.1	7.0	0.25	
	1998.10		4.0	1.1	7.0	0.15	
Euro III	1999.10, EEVs only	ESC & ELR	1.5	0.25	2.0	0.02	0.15
	2000.10	ESC & ELR	2.1	0.66	5.0	0.10	0.8 0.13*
Euro IV	2005.10		1.5	0.46	3.5	0.02	0.5
Euro V	2008.10		1.5	0.46	2.0	0.02	0.5

for engines of less than 0.75 dm³ swept volume per cylinder and a rated power speed of more than 3000 min⁻¹

EEV – Enhanced environmentally friendly vehicle; ESC – European Stationary Cycle; ETC – European Transient Cycle; ELR – European Load Response test; ECE R-49 - steady-state diesel engine test cycle introduced by ECE Regulation No 49.

Source <http://www.dieselnet.com/standards/eu/hd.html> as on September 3, 2002

Annex 3.2 Emission standards in US

Cars and light duty vehicles

Federal standards

There are two sets of standards, Tier 1 and Tier 2 that have been defined for light-duty vehicles in the Clean Air Act Amendments of 1990. The Tier 1 regulations were fully implemented in 1997. The Tier 2 standards were adopted on December 21, 1999, to be phased-in beginning in 2004.

Tier 1 Standards

Tier 1 light-duty standards apply to all new light duty vehicles (LDV), such as passenger cars, light duty trucks, sport utility vehicles (SUV), minivans and pick-up trucks. The LDV category includes all vehicles of less than 8500 lb gross vehicle weight rating, or GVWR (i.e., vehicle weight plus rated cargo capacity).

LDVs are further divided into the following sub-categories:

- Passenger cars
- Light light-duty trucks (LLDT), below 6000 lbs GVWR
- Heavy light-duty trucks (HLDT), above 6000 lbs GVWR

The Tier 1 standards were phased-in progressively between 1994 and 1997. They apply to a full vehicle useful life of 100,000 miles (effective 1996). The regulation also defines an intermediate standard to be met over a 50,000 miles period. The difference between diesel and gasoline car standards is a more relaxed NO_x limit for diesels, which applies to vehicles through 2003 model year. The details of the emission standards are given in the Table 3.7.

Table 3.7 EPA Tier 1 Emission Standards for Passenger Cars and Light-Duty Trucks, FTP 75, g/mi

Category	g/mi											P
	50,000 miles/5 years						100,000 miles/10 years ¹					
	THC	NMHC	CO	NOx		PM	THC	NMHC	CO	NOx		
				diesel	gasoline					diesel	gasoline	
Passenger cars	0.41	0.25	3.4	1	0.4	0.08	-	0.31	4.2	1.25	0.6	0
LLDT, LVW <3,750	-	0.25	3.4	1	0.4	0.08	0.8	0.31	4.2	1.25	0.6	0
LLDT, LVW >3,750	-	0.32	4.4	-	0.7	0.08	0.8	0.4	5.5	0.97	0.97	0
HLDT, ALVW <5,750	0.32	-	4.4	-	0.7	-	0.8	0.46	6.4	0.98	0.98	0
HLDT, ALVW >5,750	0.39	-	5	-	1.1	-	0.8	0.56	7.3	1.53	1.53	0

1 - Useful life 120,000 miles/11 years for all HLDT standards and for THC standards for LDT

Abbreviations:

LVW - loaded vehicle weight (curb weight + 300 lbs)

ALVW - adjusted LVW (the numerical average of the curb weight and the GVWR)

LLDT - light light-duty truck (below 6,000 lbs GVWR)

HLDT - heavy light-duty truck (above 6,000 lbs GVWR)

Source <http://www.dieselnet.com/standards/us/light.html#cal> as on September 2, 02.

Tier 2 Standards

The Tier 2 standards bring significant emission reductions relative to the Tier 1 regulation. In addition to more stringent numerical emission limits, the regulation introduces a number of important changes that make the standard more stringent for larger vehicles. Under the Tier 2 standard, the same emission standards apply to all vehicle weight categories, i.e., cars, minivans, light duty trucks, and SUVs have the same emission limit. Since light-duty emission standards are expressed in grams of pollutants per mile, large engines (such as those used in light trucks or SUVs) will have to utilize more advanced emission control technologies than smaller engines in order to meet the standard. In Tier 2, the applicability of light-duty emission standards has been extended to cover some of the heavier vehicle categories. The Tier 1 standards applied to vehicles up to 8500 lbs GVWR. The Tier 2 standard applies to all vehicles that were covered by Tier 1 and, additionally, to “medium-duty passenger vehicles” (MDPV). The MDPV is a new class of vehicles that are rated between 8,500 and 10,000 GVWR and are used for personal transportation. This category includes primarily larger SUVs and passenger vans. Engines in commercial vehicles above 8500 lbs GVWR, such as cargo vans or light trucks, will continue to certify to heavy-duty engine emission standards.

The emission limits that apply to all vehicles are fuel neutral. That is, vehicles fueled by gasoline, diesel, or alternative fuels all must meet the same standards.

The Tier 2 tailpipe standards are structured into 8 certification levels of different stringency, called “certification bins”, and an average fleet standard for NO_x emissions. Vehicle manufacturers will have a choice to certify particular vehicles to any of the 8 bins. At the same time, the average NO_x emissions of the entire vehicle fleet sold by each manufacturer will have to meet the average NO_x standard of 0.07 g/mi.

Additional temporary certification bins (bin 9, 10, and an MDPV bin) of more relaxed emission limits will be available in the transition period. These bins will expire after 2008 model year.

The Tier 2 standards will be phased-in between 2004 and 2009. For new passenger cars and light LDTs, Tier 2 standards will phase in beginning in 2004, with the standards to be fully phased in by 2007. For heavy LDTs and MDPVs, the Tier 2 standards will be phased in beginning in 2008, with full compliance in 2009. During the phase-in period from 2004-2007, all passenger cars and light LDTs not certified to the primary Tier 2 standards will have to meet an interim average standard of 0.30 g/mi NO_x, equivalent to the current NLEV standards

for LDVs. During the period 2004-2008, heavy LDTs and MDPVs not certified to the final Tier 2 standards will phase in to an interim program with an average standard of 0.20 g/mi NO_x, with those not covered by the phase-in meeting a per-vehicle standard (i.e., an emissions "cap") of 0.60 g/mi NO_x (for HLDTs) and 0.90 g/mi NO_x (for MDPVs).

The emission standards for all pollutants (certification bins) are give in the Table 3.8. The vehicle "full useful life" period has been extended to 120,000 miles.

Table 3.8 Tier 2 Emission Standards, FTP 75 g/mi

Bin#	50,000 miles					120,000 miles				
	NMOG	CO	NO _x	PM	HCHO	NMOG	CO	NO _x *	PM	HCHO
Temporary Bins										
MDPV ^c						0.28	7.3	0.9	0.12	0.032
10 ^{a, b, d}	0.125 (0.160)	3.4 (4.4)	0.4	-	0.015 (0.018)	0.156 (0.230)	4.2 (6.4)	0.6	0.08	0.018
9 ^{a, b, e}	0.075 (0.140)	3.4	0.2	-	0.015	0.090 (0.180)	4.2	0.3	0.06	0.018
Permanent Bins										
8 ^b	0.100 (0.125)	3.4	0.14	-	0.015	0.125 (0.156)	4.2	0.2	0.02	0.018
7	0.075	3.4	0.11	-	0.015	0.09	4.2	0.15	0.02	0.018
6	0.075	3.4	0.08	-	0.015	0.09	4.2	0.1	0.01	0.018
5	0.075	3.4	0.05	-	0.015	0.09	4.2	0.07	0.01	0.018
4	-	-	-	-	-	0.07	2.1	0.04	0.01	0.011
3	-	-	-	-	-	0.055	2.1	0.03	0.01	0.011
2	-	-	-	-	-	0.01	2.1	0.02	0.01	0.004
1	-	-	-	-	-	0	0	0	0	0

* - average manufacturer fleet NO_x standard is 0.07 g/mi

a - Bin deleted at end of 2006 model year (2008 for HLDTs)

b - The higher temporary (given in brackets) NMOG, CO and HCHO values apply only to HLDTs and expire after 2008

c - An additional temporary bin restricted to MDPVs, expires after model year 2008

d - Optional temporary NMOG standard of 0.195 g/mi (50,000) and 0.280 g/mi (120,000) applies for qualifying LDT4s and MDPVs only

e - Optional temporary NMOG standard of 0.100 g/mi (50,000) and 0.130 g/mi (120,000) applies for qualifying LDT2s only

f - 50,000 mile standard optional for diesels certified to bin 10

Source <http://www.dieselnet.com/standards/us/light.html#cal> as on September 2, 02.

California Standards

Current Tier 1/Low Emission Vehicle (LEV) California emission standards extend through the year 2003. More stringent LEV II regulations would become effective from 2004.

Low emission vehicle (LEV) Standards

The current California emission standards are expressed through the following emission categories:

- Tier 1
- Transitional Low Emission Vehicles (TLEV)
- Low Emission Vehicles (LEV)
- Ultra Low Emission Vehicles (ULEV)
- Super Ultra Low Emission Vehicles (SULEV)
- Zero Emission Vehicles (ZEV)

Table 3.9 summarizes the California ARB standards for new light duty vehicles. Car manufacturers are required to produce a percentage of vehicles which adhere to increasingly more stringent emission categories. After 2003, Tier 1 and TLEV standards will be eliminated as available emission categories. From 2004 onwards, the LEV II requirements begin.

The same standards for gaseous pollutants apply to diesel- and gasoline-fueled vehicles. PM standards apply to diesel vehicles only. Emission standards for medium-duty vehicles are summarized in Table 3.10.

Table 3.9 California Emission Standards for Light-Duty Vehicles, FTP 75, g/mi

Category	50,000 miles/5 years					100,000 miles/10 years				
	NMOG ^a	CO	NOx	PM	HCHO	NMOG ^a	CO	NOx	PM	HCHO
Passenger Cars										
Tier 1	0.25	3.4	0.4	0.08	-	0.31	4.2	0.6	-	-
TLEV	0.125	3.4	0.4	-	0.015	0.156	4.2	0.6	0.08	0.018
LEV	0.075	3.4	0.2	-	0.015	0.09	4.2	0.3	0.08	0.018
ULEV	0.04	1.7	0.2	-	0.008	0.055	2.1	0.3	0.04	0.011
LDT1, LVW <3,750 lbs										
Tier 1	0.25	3.4	0.4	0.08	-	0.31	4.2	0.6	-	-
TLEV	0.125	3.4	0.4	-	0.015	0.156	4.2	0.6	0.08	0.018
LEV	0.075	3.4	0.2	-	0.015	0.09	4.2	0.3	0.08	0.018
ULEV	0.04	1.7	0.2	-	0.008	0.055	2.1	0.3	0.04	0.011
LDT2, LVW >3,750 lbs										
Tier 1	0.32	4.4	0.7	0.08	-	0.4	5.5	0.97	-	-
TLEV	0.16	4.4	0.7	-	0.018	0.2	5.5	0.9	0.1	0.023 ^a
LEV	0.1	4.4	0.4	-	0.018	0.13	5.5	0.5	0.1	0.023
ULEV	0.05	2.2	0.4	-	0.009	0.07	2.8	0.5	0.05	0.013

a - NMHC for all Tier 1 standards

Abbreviations:

LVW - loaded vehicle weight (curb weight + 300 lbs)

LDT - light-duty truck

NMOG - non-methane organic gases

HCHO - formaldehyde

Source <http://www.dieselnet.com/standards/us/light.html#cal> as on September 2, 02.

Table 3.10 California Emission Standards for Medium-Duty Vehicles, FTP 75, g/mi

Category	50,000 miles/5 years					120,000 miles/11 years				
	NMOG ^a	CO	NOx	PM	HCHO	NMOG ^a	CO	NOx	PM	HCHO
MDV1, 0-3750 lbs										
Tier 1	0.25	3.4	0.4	-	-	0.36	5	0.55	0.08	-
LEV	0.125	3.4	0.4	-	0.015	0.18	5	0.6	0.08	0.022
ULEV	0.075	1.7	0.2	-	0.008	0.107	2.5	0.3	0.04	0.012
MDV2, 3751-5750 lbs										
Tier 1	0.32	4.4	0.7	-	-	0.46	6.4	0.98	0.1	-
LEV	0.16	4.4	0.4	-	0.018	0.23	6.4	0.6	0.1	0.027
ULEV	0.1	4.4	0.4	-	0.009	0.143	6.4	0.6	0.05	0.013
SULEV	0.05	2.2	0.2	-	0.004	0.072	3.2	0.3	0.05	0.006
MDV3, 5751-8500 lbs										
Tier 1	0.39	5	1.1	-	-	0.56	7.3	1.53	0.12	-
LEV	0.195	5	0.6	-	0.022	0.28	7.3	0.9	0.12	0.032
ULEV	0.117	5	0.6	-	0.011	0.167	7.3	0.9	0.06	0.016
SULEV	0.059	2.5	0.3	-	0.006	0.084	3.7	0.45	0.06	0.008
MDV4, 8501-10,000 lbs										
Tier 1	0.46	5.5	1.3	-	0.028	0.66	8.1	1.81	0.12	-
LEV	0.23	5.5	0.7	-	0.028	0.33	8.1	1	0.12	0.04
ULEV	0.138	5.5	0.7	-	0.014	0.197	8.1	1	0.06	0.021
SULEV	0.069	2.8	0.35	-	0.007	0.1	4.1	0.5	0.06	0.01
MDV5, 10,001-14,000 lbs										
Tier 1	0.6	7	2	-	-	0.86	10.3	2.77	0.12	-
LEV	0.3	7	1	-	0.036	0.43	10.3	1.5	0.12	0.052
ULEV	0.18	7	1	-	0.018	0.257	10.3	1.5	0.06	0.026
SULEV	0.09	3.5	0.5	-	0.009	0.13	5.2	0.7	0.06	0.013

a - NMHC for all Tier 1 standards

Abbreviations:

MDV - medium-duty vehicle (the maximum GVWR from 8,500 to 14,000 lbs). The MDV category is divided into five classes, MDV1 .. MDV5, based on vehicle test weight. The definition of "test weight" in California is identical to the Federal ALVW.

NMOG - non-methane organic gases

HCHO - formaldehyde

Source <http://www.dieselnet.com/standards/us/light.html#cal> as on September 2, 02

Low Emission Vehicle II (LEV II) Standards

The LEV II emission standards were adopted by the ARB in November, 1998.

These standards would become effective from the year 2004 until 2010.

Under the LEV II regulation, the light-duty truck and medium-duty vehicle categories of below 8500 lbs gross weight are reclassified and will have to meet passenger car requirements, as shown in Table 3.11. As a result, most pick-up

trucks and sport utility vehicles will be required to meet the passenger car emission standards. The reclassification will be phased in by the year 2007. Medium duty vehicles above 8500 lbs gross weight (old MDV4 and MDV5) will still certify to the medium-duty vehicle standard (Table 3.12).

Under the LEV II standard, NOx and PM standards for all emission categories are significantly tightened. The same standards apply to both gasoline and diesel vehicles (under revisions adopted on November 15, 2001 gasoline vehicles are no longer exempted from the PM standard). Light-duty LEVs and ULEVs will certify to a 0.05 g/mi (0.031 g/km) NOx standard, to be phased-in starting with the 2004 model year. A full useful life PM standard of 0.010 g/mi (0.006 g/km) is introduced for light-duty diesel vehicles and trucks less than 8500 lbs gross weight certifying to LEV, ULEV, and SULEV standards. The TLEV emission category has been eliminated in the final regulatory text.

Table 3.11 California LEV II Emission Standards, Passenger Cars and LDVs < 8500 lbs, g/mi

Category	50,000 miles/5 years					120,000 miles/11 years				
	NMOG	CO	NOx	PM	HCHO	NMOG	CO	NOx	PM	HCHO
LEV	0.075	3.4	0.05	-	0.015	0.09	4.2	0.07	0.01	0.018
ULEV	0.04	1.7	0.05	-	0.008	0.055	2.1	0.07	0.01	0.011
SULEV	-	-	-	-	-	0.01	1	0.02	0.01	0.004

Source <http://www.dieselnet.com/standards/us/light.html> as on September 2, 2002

Table 3.12 California LEV II Emission Standards, Medium Duty Vehicles, Durability 120,000 miles, g/mi

Weight (GVWR),	Category	NMOG	CO	NOx	PM	HCHO
8,500 - 10,000	LEV	0.195	6.4	0.2	0.12	0.032
	ULEV	0.143	6.4	0.2	0.06	0.016
	SULEV	0.1	3.2	0.1	0.06	0.008
10,001 - 14,000	LEV	0.23	7.3	0.4	0.12	0.04
	ULEV	0.167	7.3	0.4	0.06	0.021
	SULEV	0.117	3.7	0.2	0.06	0.01

Source. <http://www.dieselnet.com/standards/us/light.html> as on September 2, 2002

Heavy-duty vehicles

Emission limits for heavy duty engines were originally set in 1970 and, in the 1977 Clean Air Act, stringent reductions in HC and CO emissions were proposed to take effect in 1981. However, these standards were deferred until technology was available and were finally implemented in 1987, requiring catalysts on heavy-duty gasoline engines. Further reductions in NOx and diesel particulate limits, implemented from 1990 to 1995, required 3-way catalysts for heavy duty gasoline engines and radical changes in diesel engine technology.

Heavy-duty vehicles are defined as vehicles of GVWR (gross vehicle weight rating) of above 8,500 lbs in the federal jurisdiction and above 14,000 lbs in California (model year 1995 and later). Diesel engines used in heavy-duty vehicles are further divided into service classes by GVWR, as follows.

- Light heavy-duty diesel engines: $8,500 < \text{LHDDE} < 19,500$ ($14,000 < \text{LHDDE} < 19,500$ in California, 1995+)
- Medium heavy-duty diesel engines: $19,500 \leq \text{MHDDE} \leq 33,000$
- Heavy heavy-duty diesel engines (including urban bus): $\text{HHDDE} > 33,000$

The US standards apply over the "useful life" of the vehicle. The useful life is defined for each category of vehicle over the distance travelled or by the age.

Model year 1988-2003

Model year 1988-2003 US federal (EPA) and 1987-2003 California (ARB) emission standards for heavy-duty diesel truck and bus engines are summarized in Tables 3.13 and 3.14. The sulphur content in the certification fuel was reduced to 500 ppm from 1994 onwards.

Table 3.13 EPA Emission Standards for Heavy-Duty Diesel Engines, g/bhp·hr

	HC	CO	NOx	PM
Heavy-Duty Diesel Truck Engines				
1988	1.3	15.5	10.7	0.6
1990	1.3	15.5	6	0.6
1991	1.3	15.5	5	0.25
1994	1.3	15.5	5	0.1
1998	1.3	15.5	4	0.1
Urban Bus Engines				
1991	1.3	15.5	5	0.25
1993	1.3	15.5	5	0.1
1994	1.3	15.5	5	0.07
1996	1.3	15.5	5	0.05*
1998	1.3	15.5	4	0.05*

* - in-use PM standard 0.07

Source: <http://www.dieselnet.com/standards/us/hd.html> as on September 2, 02.

trucks and sport utility vehicles will be required to meet the passenger car emission standards. The reclassification will be phased in by the year 2007. Medium duty vehicles above 8500 lbs gross weight (old MDV4 and MDV5) will still certify to the medium-duty vehicle standard (Table 3.12).

Under the LEV II standard, NOx and PM standards for all emission categories are significantly tightened. The same standards apply to both gasoline and diesel vehicles (under revisions adopted on November 15, 2001 gasoline vehicles are no longer exempted from the PM standard). Light-duty LEVs and ULEVs will certify to a 0.05 g/mi (0.031 g/km) NOx standard, to be phased-in starting with the 2004 model year. A full useful life PM standard of 0.010 g/mi (0.006 g/km) is introduced for light-duty diesel vehicles and trucks less than 8500 lbs gross weight certifying to LEV, ULEV, and SULEV standards. The TLEV emission category has been eliminated in the final regulatory text.

Table 3.11 California LEV II Emission Standards, Passenger Cars and LDVs < 8500 lbs, g/mi

Category	50,000 miles/5 years					120,000 miles/11 years				
	NMOG	CO	NOx	PM	HCHO	NMOG	CO	NOx	PM	HCHO
LEV	0.075	3.4	0.05	-	0.015	0.09	4.2	0.07	0.01	0.018
ULEV	0.04	1.7	0.05	-	0.008	0.055	2.1	0.07	0.01	0.011
SULEV	-	-	-	-	-	0.01	1	0.02	0.01	0.004

Source <http://www.dieselnet.com/standards/us/light.html> as on September 2, 2002

Table 3.12 California LEV II Emission Standards, Medium Duty Vehicles, Durability 120,000 miles, g/mi

Weight (GVWR),	Category	NMOG	CO	NOx	PM	HCHO
8,500 - 10,000	LEV	0.195	6.4	0.2	0.12	0.032
	ULEV	0.143	6.4	0.2	0.06	0.016
	SULEV	0.1	3.2	0.1	0.06	0.008
10,001 - 14,000	LEV	0.23	7.3	0.4	0.12	0.04
	ULEV	0.167	7.3	0.4	0.06	0.021
	SULEV	0.117	3.7	0.2	0.06	0.01

Source. <http://www.dieselnet.com/standards/us/light.html> as on September 2, 2002

Heavy-duty vehicles

Emission limits for heavy duty engines were originally set in 1970 and, in the 1977 Clean Air Act, stringent reductions in HC and CO emissions were proposed to take effect in 1981. However, these standards were deferred until technology was available and were finally implemented in 1987, requiring catalysts on heavy-duty gasoline engines. Further reductions in NOx and diesel particulate limits, implemented from 1990 to 1995, required 3-way catalysts for heavy duty gasoline engines and radical changes in diesel engine technology.

Heavy-duty vehicles are defined as vehicles of GVWR (gross vehicle weight rating) of above 8,500 lbs in the federal jurisdiction and above 14,000 lbs in California (model year 1995 and later). Diesel engines used in heavy-duty vehicles are further divided into service classes by GVWR, as follows.

- Light heavy-duty diesel engines: $8,500 < \text{LHDDE} < 19,500$ ($14,000 < \text{LHDDE} < 19,500$ in California, 1995+)
- Medium heavy-duty diesel engines: $19,500 \leq \text{MHDDE} \leq 33,000$
- Heavy heavy-duty diesel engines (including urban bus): $\text{HHDDE} > 33,000$

The US standards apply over the "useful life" of the vehicle. The useful life is defined for each category of vehicle over the distance travelled or by the age.

Model year 1988-2003

Model year 1988-2003 US federal (EPA) and 1987-2003 California (ARB) emission standards for heavy-duty diesel truck and bus engines are summarized in Tables 3.13 and 3.14. The sulphur content in the certification fuel was reduced to 500 ppm from 1994 onwards.

Table 3.13 EPA Emission Standards for Heavy-Duty Diesel Engines, g/bhp·hr

	HC	CO	NOx	PM
Heavy-Duty Diesel Truck Engines				
1988	1.3	15.5	10.7	0.6
1990	1.3	15.5	6	0.6
1991	1.3	15.5	5	0.25
1994	1.3	15.5	5	0.1
1998	1.3	15.5	4	0.1
Urban Bus Engines				
1991	1.3	15.5	5	0.25
1993	1.3	15.5	5	0.1
1994	1.3	15.5	5	0.07
1996	1.3	15.5	5	0.05*
1998	1.3	15.5	4	0.05*

* - in-use PM standard 0.07

Source: <http://www.dieselnets.com/standards/us/hd.html> as on September 2, 02.

Table 3.14 California Emission Standards for Heavy-Duty Diesel Engines, g/bhp-hr

Year	NMHC	THC	CO	NOx	PM
Heavy-Duty Diesel Truck Engines					
1987	-	1.3	15.5	6	0.6
1991	1.2	1.3	15.5	5	0.25
1994	1.2	1.3	15.5	5	0.1
Urban Bus Engines					
1991	1.2	1.3	15.5	5	0.1
1994	1.2	1.3	15.5	5	0.07
1996	1.2	1.3	15.5	4	0.05

Source: <http://www.dieselnet.com/standards/us/hd.html> as on September 2, 02.

Model Year 2004 and Later

In October 1997, EPA adopted new emission standards for model year 2004 and later heavy-duty diesel truck and bus engines. These standards are as per the provisions of the Statement of Principles (SOP) signed in 1995 by the EPA, California ARB, and the manufacturers of heavy-duty diesel engines. The goal was to reduce NOx emissions from highway heavy-duty engines to levels approximately 2.0 g/bhp-hr beginning in 2004. Manufacturers have the flexibility to certify their engines to one of the two options shown in Table 3.15.

Table 3.15 EPA Emission Standards for MY 2004 and Later HD Diesel Engines, g/bhp-hr

Option	NMHC + NOx	NMHC
1	2.4	n/a
2	2.5	0.5

Source <http://www.dieselnet.com/standards/us/hd.html> as on September 2, 02.

In October 1998, a Consent Decree was designed between the EPA, Department of Justice, California ARB and engine manufacturers over the issue of high NOx emissions from heavy duty diesel engines. The provisions of this Decree include civil penalties for engine manufacturers and requirements to allocate funds for pollution research, upgrading existing engines to lower NOx emissions and meeting the 2004 emission standards by October 2002.

Model Year 2007 and Later

On December 21, 2000 the EPA signed emission standards for model year 2007 and later heavy-duty highway engines (the California ARB adopted virtually identical 2007 heavy-duty engine standards in October 2001). The rule includes two components: (1) emission standards, and (2) diesel fuel regulation.

The first component of the regulation introduces new, very stringent emission standards, as follows:

- PM - 0.01 g/bhp-hr (0.013 g/kw-hr)
- NOx - 0.20 g/bhp-hr (0.27 g/kw-hr)
- NMHC - 0.14 g/bhp-hr (0.19 g/kw-hr)

The PM emission standard will take full effect in the 2007 heavy-duty engine model year. The NOx and NMHC standards will be phased in for diesel engines between 2007 and 2010. The phase-in would be on a percent-of-sales basis: 50% from 2007 to 2009 and 100% in 2010 (gasoline engines are subject to these standards based on a phase-in requiring 50% compliance in 2008 and 100% compliance in 2009).

The diesel fuel regulation limits the sulphur content in on-highway diesel fuel to 15 ppm with effect from June 1, 2006. The refiners can take advantage of a temporary compliance option that will allow them to continue producing 500 ppm fuel in 20% of the volume of diesel fuel they produce until December 31, 2009. In addition, refiners can participate in an averaging, banking and trading program with other refiners in their geographic area.

Annex 3.3 Emission standards in Japan

Table 3.16 Motor vehicle exhaust emission standards in Japan

Vehicle type	Inertia weight	Units	NOx	NMHC	CO	PM
Diesel passenger vehicle	EIW<1250 kg and 1250 kg	G/km	0.14	0.024	0.63	0.013
	EIW>1250 kg	G/km	0.15	0.024	0.63	0.014
Diesel trucks and buses	GVW<1750 kg and 1750 kg	G/km	0.14	0.024	0.63	0.013
	1750 kg < GVW < 3500 kg and 3500 kg	G/km	0.25	0.024	0.63	0.015
	3500 kg < GVM	G/kWh	2.0	0.17	2.22	0.027
Gasoline passenger vehicle	All	G/km	0.05	0.05	1.15	NA
Gasoline light duty vehicles	All	G/km	0.05	0.05	1.02	NA
Gasoline trucks and buses	GVW<1750 kg and 1750 kg	G/km	0.05	0.05	1.15	NA
	1750 kg < GVW < 3500 kg and 3500 kg	G/km	0.07	0.05	2.55	NA
	3500 kg < GVW	G/kWh	0.7	0.23	16.0	NA

EIW= Equivalent Inertia Weight, GVW = Gross Vehicle Weight

Source Carlines April, 2002; <http://www.env.go.jp/en/ieg/v007-02.html> as on September 3, 02

Table 3.17 Vehicle exhaust emission standards in Japan till 1999

Category			Mode		Regulation		Remarks		
				Components	Enforcement	Standard			
					year	value			
Gasoline and LPG motor vehicles	Passenger cars	4-cycled and 2-cycled	10-15M (g/km)	CO	1975	2.70 (2.10)	Currently 2-cycled passenger cars are not manufactured.		
				HC	1975	0.39 (0.25)			
				NOx	1978	0.48 (0.25)			
		11M (g/test)	CO	1975	85.0 (60.0)				
			HC	1975	9.50 (7.00)				
			NOx	1978	6.00 (4.40)				
		Trucks and buses	4-cycled mini-sized motor vehicles	10-15M (g/km)	CO	1998		8.42 (6.50)	
					HC	1998		0.39 (0.25)	
					NOx	1998		0.48 (0.25)	
	11M (g/test)		CO	1998	104 (76)				
			HC	1998	9.50 (7.00)				
			NOx	1998	6.00 (4.40)				
	2-cycled mini-sized motor vehicles		10-15M (g/km)	CO	1975	17.0 (13.0)	Currently these vehicles are not manufactured		
				HC	1975	15.0 (12.0)			
				NOx	1975	0.50 (0.30)			
		11M (g/test)	CO	1975	130 (100)				
			HC	1975	70.0 (50.0)				
			NOx	1975	4.00 (2.50)				

Diesel motor vehicles	Passenger cars	Light-duty vehicles (GVW \leq 1.7t)	10-15M	(g/km)	CO	1988	2.70 (2.10)	
					HC	1988	0.39 (0.25)	
					NOx	1988	0.48 (0.25)	
			11M	(g/test)	CO	1988	85.0 (60.0)	
					HC	1988	9.50 (7.00)	
					NOx	1988	6.00 (4.40)	
		Medium-duty vehicles (1.7t < GVW \leq 2.5t)	10-15M	(g/km)	CO	1998	8.42 (6.50)	
					HC	1998	0.39 (0.25)	
					NOx	1994	0.63 (0.40)	
			11M	(g/test)	CO	1998	104 (76)	
					HC	1998	9.50 (7.00)	
					NOx	1994	6.60 (5.00)	
		Heavy-duty vehicles (2.5t < GVW)	G13M	(g/kWh)	CO	1998	68.0 (51.0)	LPG-fueled 105(76)
					HC	1998	2.29 (1.80)	
					NOx	1995	5.90 (4.50)	
					CO	1986	2.70 (2.10)	
					HC	1986	0.62 (0.40)	
					NOx	Small Medium	1997 1998	0.55 (0.40) 0.55 (0.40)
					PM	1997, 1998	0.14 (0.08)	Small 1997, Medium 1998
Trucks and buses		Light-duty vehicles (GVW \leq 1.7t)	10-15M	(g/km)	CO	1988	2.70 (2.10)	
					HC	1988	0.62 (0.40)	
					NOx	1997	0.55 (0.40)	
					PM	1997	0.14 (0.08)	
					CO	1993	2.70 (2.10)	
					HC	1993	0.62 (0.40)	
		Medium-duty vehicles (1.7t < GVW \leq 2.5t)	10-15M	(g/km)	NOx	1997, 1998	0.97 (0.70)	MTM 1997
					PM	1997, 1998	0.18 (0.09)	ATM 1998
					CO	1994	9.20 (7.40)	
					HC	1994	3.80 (2.90)	
					NOx	DI IDI	1997, 1998, 1999	5.80 (4.50) GVW \leq 3.5t, 1997 3.5t < GVW \leq 12t, 1998
					PM	1997, 1998, 1999	0.49 (0.25)	12t < GVW, 1999

Two-wheeled motor vehicles	4-cycled	Two-wheeled motor vehicles	CO	1998, 1999	20.0 (13.0)
			HC	1998, 1999	2.93 (2.00)
		(g/km)	NOx	1998, 1999	0.51 (0.30)
	2-cycled	Two-wheeled motor vehicles	CO	1998, 1999	14.4 (8.00)
			HC	1998, 1999	5.26 (3.00)
		(g/km)	NOx	1998, 1999	0.14 (0.10)

carbon monoxide(CO), hydrocarbons(HC), nitrogen oxides(NOx), particulate matter(PM)
Standard value "2.70(2.10)" means that the maximum permissible limit per unit is 2.70 and the average permissible limit for each category of motor vehicle is 2.10.

10□15M means 10□15-mode cycle which reflects an average driving pattern in cities. "11M" means 11-mode cycle which reflects a driving pattern of vehicles which make a cold start to drive to cities from outside cities

As for diesel-powered passenger cars, "small" vehicle means a vehicle with equivalent initial weight (EIW) of 1.25t or less, "medium" vehicle means a vehicle with EIW of more than 1.25t. "MTM" and "ATM" stand for manual transmission and automatic transmission respectively. "ID" and "IDI" stand for direct injection and indirect injection respectively.

Source: <http://www.env.go.jp/en/jeg/v007-02.html> as on September 3, 02.

Annex 3.4 Emission standards in India

Mass emission norms for vehicles

Table 3.18 Petrol Vehicles

Three - Wheelers			
(g/km)			
Year	CO	HC	HC + Nox
1991	12 - 30	8 - 12	-
1996	6.75	-	5.40
2000	4.00	-	2.00

Two - Wheelers			
(g/km)			
Year	CO	HC	HC + Nox
1991	12 - 30	8 - 12	-
1996	4.50	-	3.60
2000	2.00 *	-	2.00

Car			
(g/km)			
Year	CO	HC	HC + Nox
1991	14.3 - 27.1	2.0 - 2.9	
1996	8.68 - 12.4	..	3.00 - 4.36
1998*	4.34 - 6.20	..	1.50 - 2.18
2000	2.72	..	0.97
B.S II	2.2	..	0.5
B.S II	2.2 - 5.0	..	0.5 - 0.7

* For Catalytic Converter Fitted vehicles

upto 6 seaters & GVW upto 2.5 tons More than 6 seaters & GVW upto 3.5 tons

Table 3.19 Diesel Vehicles

Diesel Vehicles (GVW Upto 3.5 Tons)				
(g/ kwh)	Engine Dynamometer			
Year	CO	HC	NOx	PM
1992	14	3.5	18	
1996	11.20	2.40	14.4	
2000	4.5	1.1	8.0	0.36/0.61 #
B.S II	4.0	1.1	7.0	0.15

or

(g/km)	Chassis Dynamometer				
Year	CO	HC	HC + NOx	PM	
1992	17.3 - 32.6	2.7 - 3.7	.	.	Light Duty Vehicles
1996	5.0 - 9.0	.	2.0 - 4.0	.	.
2000	2.72 - 6.90	.	0.97 - 1.70	0.14 - 0.25	
B.S II	1.0 - 1.5	.	0.7 - 1.2	0.08 - 0.17	

Cars

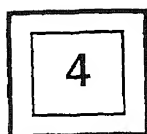
(g/km)	Chassis Dynamometer				
B.S. II	1.0	.	0.7	0.08	upto 6 seaters & GVW upto 2.5 tons
B.S. II	1.0 - 1.5	.	0.7 - 1.2	0.08 - 0.17	More than 6 seaters & GVW upto 3.5 tons

Diesel Vehicles (GVW > 3.5 Tons)

(g/ kwh)					
Year	CO	HC	NOx	PM	
1992	17.3 - 32.6	2.7 - 3.7	.	.	
1996	11.20	2.40	14.4	.	
2000	4.5	1.1	8.0	0.36/ 0.36 #	
B.S II	4.0	1.1	7.0	0.15	

For Engines with Power exceeding 85 kw/ For engines with power upto 85 kw

Source: <http://www.siamindia.com/> as on 1st August 2002



Fuel quality and alternative fuels

Introduction

The growing focus on ambient air quality and the significant effect that vehicular emissions have on the ambient air quality has led to major changes in the technologies associated with automobiles apart from various strategies related to managing the transport system as a whole. These technologies include the fuel used for combustion, the technologies for internal combustion and post combustion emissions control devices. The conventional fuels consisting mainly of diesel and gasoline have undergone major changes in quality to ensure reduced emissions due to combustion. To further reduce emissions both local and global level, many alternate fuels like gaseous and bio-fuels have emerged based on the regional concerns of specific pollutants. The discussion on fuels, which broadly covers their future development and the factors affecting their development have been broadly classified based on the three categories, listed below:

Conventional Fuels

- Diesel
- Gasoline

Gaseous Fuels

- CNG
- LPG

Renewable Fuels

- Ethanol
- Bio-diesel

The policy recommended for auto fuels by the Mashelkar Committee and its implications in the light of the EPCA report on similar subject has been analysed in this chapter in detail.

Who specifies standards for fuels in India?

The Fuels Sub-Committee of the Bureau of Indian Standards, which has members from the oil and automotive industry, notifies the fuel specifications in India from time to time based on the emission norms which are changed and notified in the Motor Vehicles Act. The Supreme Court of India constituted a committee in 1986, under the EPCA (Environment Pollution (Prevention and Control) Authority for the National Capital Region) Act, which in the recent past has initiated number of changes in the fuel quality. Changes such as phasing out of unleaded gasoline, introduction of EURO II grade diesel and petrol in metros etc are actions initiated by the Court. The Ministry of Petroleum and Natural Gas in September 2001 constituted a committee under the Chairmanship of Dr. Mashelkar. This committee submitted its interim report, which was accepted in principle by the Union Cabinet. This committee is expected to submit its final report soon. The recommended changes if accepted would have to translate into changes in the BIS specifications (for fuel quality) and the Motor Vehicles Act (for emission standards).

The section below details the various quality parameters of the fuel quality, which have a bearing on the emissions and also the various changes that will take place in future.

Level of Emissions Regulation

The level of emissions regulations that are of interest today in the country is the EURO IV level (equivalent Bharat IV norms). There are further developments in the emissions regulation like the EURO V regulations, which have still not been mandated with any deadline in Europe. The EURO IV regulations which would come into force by 2005 itself are less stringent than the targeted regulations in US by the year 2007. Also since EURO III standard fuels do not allow the use of the latest emission control devices, EURO IV fuel standards are very crucial to ensure that these devices can be used effectively. Since further developments in regulations would be mainly on a fuel neutral approach, targeting such levels require significant development in vehicle technologies and also fuel quality. Hence, fuel quality and emissions technologies till the EURO IV level are only discussed.

Conventional fuels

Diesel

The quality conventional transport fuels have been changed from time to time with an attempt constantly made to reduce the components in the fuel, which result in emissions and also improve combustion properties and engine performance. The various changes that have been made to the diesel quality in Europe, which have been adopted in most of the countries in Asia also including in India are listed in Table 4.1.

Table 4.1 Future Fuel Quality Specifications

Property	EURO II	EURO III	EURO IV
Density, gm/cc	0.82-0.86	0.82-0.845	0.82-0.845
Cetane Number	48	51	51
Poly Aromatics content (PAH), wt %	NA	11	4
Sulfur, ppm (max)	500	350	50
T 95, Deg C (max)	370	360	360
Lubricity, Wear Scar Diameter, mm (max)	460	460	460
Europe Year of Implementation	1998	2000	2005
India Year of Implementation (EURO III and IV tentative)**	2000	2005	2010

NA- Not Applicable

** Proposed by the Mashelkar Committee report on Auto Fuel Policy

The properties of diesel fuel are divided into the following three categories based on the effect they have on different aspects of the engine performance:

1. Engine Performance
 - Cetane Number
2. Emissions Performance
 - Poly Aromatic Hydrocarbon (PAH)
 - Sulphur Content
 - T95
 - Density
3. Fuel Flow properties
 - Lubricity
 - Cold Filter Plugging Point
 - Cloud Point

Apart from the lubricity of the fuel the other flow related properties are not of importance in India due to the relatively hot climatic conditions in India when compared to Europe, where the cold flow properties are very critical.

Cetane Number

From Table 4.1 it is clear that the improvements in quality of diesel have resulted in making the diesel lighter thereby making it more paraffinic in terms of its molecular composition, as for the same carbon number, paraffins are the lighter of the species of hydrocarbons. This results in the increase of Cetane Number whose minimum limit has also been progressively increased. Cetane Number is a very important combustion property and has a direct bearing on the efficiency of the engine. It is also important to note that increase in Cetane Number either by changing the molecular composition of the diesel fuel or by the addition of a Cetane Improver additive are at a cost which would vary significantly between different refinery sources. The cost of improving Cetane Number by 3 numbers from EURO II to EURO III level using a Cetane improving additive will depend upon the type of additive that is used. Refinery processing to increase Cetane Number would also decrease the aromatics in the diesel fuel. The major Cetane Improver used is 2-Ethyl Hexyl Nitrate. The cost of improving Cetane Number from 48 Cetane Number to 51 Cetane Number would be only about \$ 1 /ton of diesel, which makes it economical to add CI additive to increase Cetane when compared to the hydroprocessing route to increase Cetane Number (Shell Global Solutions, 1999).

Polyaromatic Hydrocarbons (PAH) and T95

This is the most important source of particulate emissions from diesel engines, particularly in the older engines (Lee, 1998) in addition to contributing for NO_x emissions due to higher flame temperatures associated with Aromatic compounds. These are generated during some refinery secondary processes and would require significant treatment in terms of aromatic saturation to convert them to paraffinic components. The T95 point represents the percentage of heavier and bigger molecules in diesel fuel. Most of the species of the PAH are in the upper limit of the T95 and reduction in the limit for T95 would also result in the decrease in PAH content in diesel. This has also been reduced significantly in order to reduce the percentage of heavier and bigger molecules in diesel. These conclusions have been drawn in some recent studies (Nakakita, 1998; Tanaka, 1998). These changes have led to the diesel becoming lighter (reduced density) which also helps in better emissions performance. Kidoguchi et al point

out though the aromatics in diesel do not affect the combustion characteristics, they do have an effect on the particulate and nitrogen oxide emissions (Kidoguchi, 2000). As already indicated above these changes are highly cost-intensive changes, both in terms of high capital involved but more importantly, the operating costs also which result in increase in cost of production of diesel. The effect of PAH on particulate matter is illustrated in Figure 4.1 (Tanaka 1998), which shows that there is a significant impact of PAH content in diesel on PM emissions from diesel engines.

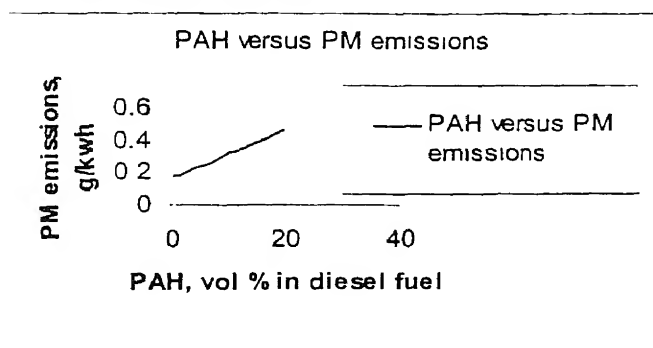


Figure 4.1 Effect of PAH content in diesel on PM emissions

Sulphur

This component in diesel fuel contributes to particulate emissions and also reduces the activity of the advanced emissions control catalysts. The effect of Sulphur content in diesel on particulate emissions from a diesel engine is schematically represented in Figure 4.2. (Stuart Neill, 2000). The effect of S in PM emissions from diesel engines is not very significant except for increased Sulphate emissions. The sulphur limit in diesel has been reduced to less than 50-ppm levels to enable the use of some advanced emission control devices. The reduction of sulphur in diesel would, again like increase in Cetane Number, be a cost intensive process. There are a few sulphur reduction technologies, which are under various stages of development, which would significantly reduce the cost of reducing sulphur in diesel.

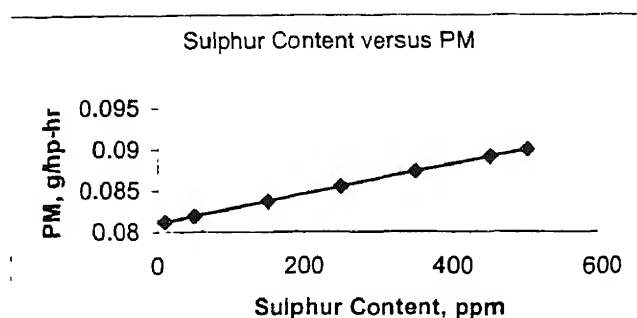


Figure 4.2 Effect of S content in diesel on Particulate Matter emissions

Lubricity

With the continuous reduction in sulphur and aromatic levels in diesel, the lubricity of diesel has also reduced significantly. This is because sulphur in diesel gives diesel the required lubricity properties. The reduction in lubricity due to significant reductions in sulphur in diesel will have to be compensated by the addition of the lubricity additive. Sulphur in diesel contributes to the lubricity in diesel, hence when sulphur levels in diesel are reduced, lubricity needs to be compensated by the addition of the additive whose dosage will vary based on the sulphur content in diesel.

The Table 4.2 summarises the effect of diesel fuel properties on Heavy-Duty Diesel Emissions (Lee, 1998)

Table 4.2 Summarised Influence of Fuel Properties on Heavy-Duty Diesel Emissions

Fuel Modification	HC	CO	NOx	PM
Reduce Sulphur	No Effect	No Effect	No Effect	Reduces (small effect) ^a
Increase Cetane	No effect ^b	No effect ^c	Small effect	No effect
Reduce PAH	Reduces (small effect)	No effect	Reduces (small effect)	Reduces (Large effect)
Reduce Density	Increases (Large effect)	Increases (small effect)	Reduces (small effect)	Reduces (Large effect) ^d

^a Very significant when sulphur reduces from 0.3 % to 0.05 % but not significant when S reduces from 0.05 % to lower levels.

^b Significant for older engines

^c Significant for older engines

^d Significant for older engines and not significant for newer engines

It is also important to note that though all emission related properties of diesel are important in the context of reducing emissions, it should be recognised in this context that the after-treatment device becomes the primary driver on tailpipe emissions. All other fuel properties will have only minor or secondary effects on the tailpipe emissions in newer engines. (Lee, 1998) The diesel fuel properties will nevertheless be very important for the older engines where the latest emission control devices cannot be fitted.

US Diesel Quality

Though the changes in emissions regulations and fuel quality in India have been largely based on the developments in Europe, it is important to understand the developments in the US also. The improvement in quality of diesel in US has been on a different path. In US with gasoline is the fuel which has a higher percentage share in the transport sector, the improvements in the quality of gasoline has been more significant than that of improvements in diesel quality apart from reduction in diesel sulfur. The improvements in gasoline quality are discussed later in this chapter. The diesel quality in US is based on a standard ASTM D 975, which is applicable in major regions, is given in the Table 4.3. Due to the cold climatic conditions in US (similar to many European countries) a lot of focus has been on the cold flow properties which are not so significant in the Indian context. Properties like the Cold Filter Plugging Point (CFPP) and Cloud Point are very important properties for diesel in US when compared to the diesel produced in other countries.

(www.chevron.com/prodserv/fuels/bulletin/diesel/L2_5_1rf.html, August 10th 2002).

Table 4.3 ASTM D 975 Diesel Specifications

Property	Low S 1-D	Low S 2-D
Flash Point, Deg C	38	52
T90, Deg C	288	338
Sulfur, %wt	0.05	0.05
Cetane Number, min	40	40
Aromaticity, %vol	35	35

The requirements given in Table 4.3 are the minimum ones required to guarantee acceptable performance for the majority of users. In addition, the specification recognizes some requirements established by the EPA to reduce

emissions. Also there are some additional constraints in order to meet product specifications for products, which are pumped in cross-country pipelines.

These fuel specifications are less stringent than the European and Japanese specifications, which have a higher minimum level of Cetane Number. Since PAH and a higher T 95 contribute significantly to particulate emissions which is the major criteria pollutant they have been significantly reduced. In US in select cities the sulphur level in diesel has been reduced in order to enable the use of particulate filters. The catalysts in these particulate filters require very low levels of sulphur. California has a separate specification for diesel fuel based on California Air Resources Boards' recommendations. Some of the manufacturers of these particulate filters recommend sulphur level as low as 10 – 15 ppm also.

Ultra low sulfur diesel (ULSD) has been introduced for Heavy-duty applications in many cities in the US in combination with diesel particulate filters (DPF), which require the use of diesel with sulfur less than 50 ppm. In Europe the ULSD meets the EURO IV specifications and in US the sulfur content is less than 50 ppm while the other properties meet the ASTM D 975 standard specifications. The sulfur in diesel has a deactivating effect on the catalysts as already discussed above on the diesel particulate filters (DPF) and to ensure that the DPFs function with maximum efficiencies in terms of particulate matter reduction efficiency. The limit on sulfur in diesel will be further made stringent to allow for use of after-treatment devices, which reduce NO_x emissions and are highly sensitive to sulfur levels. These technologies are discussed in detail in the section on emission control technologies. In the medium term till the technologies for exhaust NO_x emission reduction from diesel engines are fully commercialized, emulsified diesel either with water or ethanol are being considered as options. Though the automobile companies have pointed out some issues to be addressed in case of emulsified fuel like power loss etc, this should be a focus area for both fuel and automobile companies as many major cities like London etc have introduced this fuel for captive fleets of vehicles. There is also some particulate emission reduction benefit offered by the emulsified fuel.

Many city transit authorities in US are extensively using ULSD in combination with Continuously Regenerating Particulate filters (CRT) of Johnson Matthey and Catalytic Soot Filters (CSF) from Engelhard apart from similar products from ISUZU, Japan. A relevant is the New York City Transit, which has almost about 3500 buses fitted with these devices and are in normal operation. The public transit in London also has moved to ULSD with

particulate filters placed at the end of the exhaust pipe for the public transport. Some bus fleets in London have moved to emulsified ULSD along with diesel particulate filters in order to address the issue of NO_x control also.

There are refinery technologies available, which would help in achieving these fuel properties.

Review of policies in India

There have been numerous committees set up by the government, which have looked into the aspects of improvement required in fuel quality and the roadmap for such improvement. The important studies and their recommendations are summarised below:

1. **Hydrocarbon Vision 2025**– This report was prepared by the committee that was constituted by the Prime Minister to identify the future direction of the upstream and downstream oil and gas industry should take in terms of investments and the roadmap for total deregulation of the sector (Hydrocarbon Vision 2025, 1999). This report did not directly address the issue of fuel quality standards etc, it touched upon the issues of reduction in the cross-subsidisation between different petroleum products. It proposed a roadmap for reducing subsidies on kerosene and LPG thereby reducing the high taxation levels on gasoline and diesel. This will address partly the problem of adulteration of fuels, though not completely as until the taxation levels on gasoline and diesel are significantly higher than that on kerosene, adulteration can still be rampant.
2. **CPCB Report on Transport Fuel Quality**– There was a committee constituted by the Central Pollution Control Board whose objective was to propose a roadmap for up-grading fuel quality in the country. That committee recommended introduction of EURO III in entire country by the year 2005 in a phase wise manner (CPCB 1999).
3. **EPCA Committee**– The main recommendation of the EPCA Committee to the Supreme Court was to mandate the use of CNG for public transport vehicles in Delhi (EPCA, 2001). It also identified “unadulterable” diesel with less than 10-ppm sulphur content as the only clean fuel in addition to CNG and LPG and electricity from the aspect of local pollutants. Since the committee observed that there is a requirement of considerable lead time for producing diesel with less than 10-ppm S content, it recommended mandating CNG as the fuel for all new public transport buses and conversion of all diesel buses to CNG by retrofitment. The long chain hydrocarbons were considered to have higher emissions level when compared to the short

chain hydrocarbons like CNG and LPG. This led to the recommendation to the Apex Court to mandate the use of CNG as fuel for public transport in Delhi.

4. Mashelkar Committee – Auto Fuel Policy–

The recommended roadmap of the Mashelkar Committee report for introduction of stringent emission norms was submitted to the government only recently (Auto Fuel Policy 2001). The road map proposed by the Mashelkar Committee is given in Chapter 3.

The committee has taken a more balanced view in terms of the effect on refineries and costs to consumers but is understood to have recommended movement to EURO IV standards by 2010 in their final report. Though the principle of the committee has not been criticised, these initial recommendations drew flak from the many quarters including the Apex Court for the following reasons:

- Not considering the health costs involved in deterioration of air quality in metros due to increasing vehicular pollution for the recommendations made.
- Not recommending EURO IV norms for metros, with a note that EURO IV norms were not yet legislated in Europe itself, however it is important to note in this context that EURO IV regulations would come into force from year 2005.
- Not recommending quick changes in emission norms and fuel quality.

The first two policies discussed about the introduction of such fuels in India, the Mashelkar Committee report in addition to these aspects has also dealt with the subject of cost to refineries and cost of such fuels to the consumers. The final report of the Mashelkar committee also has indicated incremental cost upto EURO III diesel quality. The Mashelkar Committee has analysed the additional cost for different Indian refineries for producing EURO II and EURO III diesel (Mashelkar 2001). These additional costs are listed for important refineries in Table 4.4:

Table 4.4 Cost differential between current and future diesel

Refinery	Important marketing location **	EURO I to EURO II (Rs/liter)	EURO I to EURO III (Rs/liter)
IOC Mathura	Delhi	1.23	1.41
IOC Gujarat	Baroda, Ahmedabad	0.84	1.03
RPL	Delhi, Jaipur	0.25	0.90
Jamnagar			
CPCL	Chennai, Bangalore	1.30	1.60
Chennai			
HPCL	Mumbai, Pune	1.4	2.0
Mumbai			
IOC Haldia	Kolkata	1.16	1.24

** All data except important marketing location taken from Mashelkar Committee report.

The marketing locations are listed based on the minimum distance from the refinery and availability of pipeline infrastructure.

The total investment requirements to achieve EURO III fuel standards in India are Rs.350 billion rupees in two stages, first to EURO II and then to EURO III. It is to be noted that Indian refineries still do not have any estimates of the investments / costs that would be incurred for producing EURO IV fuels (diesel and gasoline).

As observed in Table 4.4, it is clear that the older refineries incur more fixed and operating cost for production of these upgraded fuels.

A CONCAWE study (CONCAWE, 1999) conducted to evaluate the cost implications for refineries with different configurations has summarised the additional cost implications for producing EURO IV diesel when compared to EURO III diesel as in Table 4.5. The costs indicated are for different levels of S in diesel and are the average for European refineries having different configurations. These values would be relevant in the Indian scenario also because of the general similarity of the configuration of most of the Indian refineries and the European refineries. There are some refineries in India like the Northeastern refineries which do not have good configuration and for which production of the advanced grades of diesel will not be economically feasible and would also require significant investments.

Table 4.5 Incremental Cost from EURO III to EURO IV

Level	Incremental Cost Rs/liter
EURO III to EURO IV (Standard Specs)	0.3
EURO IV (50-ppm S) to EURO IV (10-ppm S)	0.21
EURO III to EURO IV (10-ppm S)	0.51
EURO III to EURO IV (55 Cetane Number)	0.64

Source. Concawe 1999

These incremental costs would be incurred over and above the costs indicated for up-gradation upto EURO III level. This makes the cost of EURO IV diesel approximately about Rs.2 to 2.5 /liter more than the price of the current grade of diesel sold in metros. These incremental prices can be influenced significantly by the following factors:

1. Incentives provided for investments made in achieving these fuel quality standards.
2. Competition in the sector and pricing strategies followed which might ensure that all of this incremental cost is not passed on to the consumer in order to be competitive.
3. Competition in terms of pricing and market share from equivalent alternate fuels, which would directly affect the sales of the conventional fuels.

In this context it is also important to note the cost to the consumer of the better quality fuel could be significantly lowered by the following incentives:

- Providing incentives in the form of accelerated depreciation and waving of customs duty on capital goods imported for the product quality up-gradation.
- Having a differential taxation regime between the same fuel but meeting different standards so that the cleaner fuel is taxed less than the current grade of fuel.

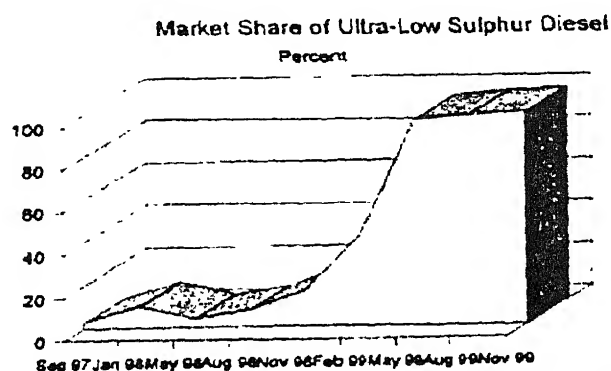
In addition to this it is also to be noted that the marketing of diesel and gasoline has been decontrolled and since the marketing companies will have the freedom to price their products based on their costs, the prices of diesel will vary significantly from place to place. The price of diesel in the current deregulated market scenario would be based on the actual cost of the products, which would depend primarily on the following factors.

- Location of the place – inland or coastal location

- Source of diesel – Refinery source that will include the additional cost for production of the upgraded quality of diesel. The areas which would depend on the Northeastern refineries will have to pay a higher price than the metropolitan cities.
- Logistic mode from source to destination – pipeline / rail / road
- Local sales tax levels – Significantly variation between different states, which creates many distortions in prices between different regions.
- Marketing Margins – This would be the major component of the price of the fuel, which will vary on the competition in the marketing sector.

In addition to all these factors which would be cost based, the competition in the sector will have a major influence in determining the final retail price of the conventional fuels.

In UK duty exemptions to refineries encouraged the refineries to start producing EURO IV grade diesel by 2000 in place of the mandated deadline of 2005. Similar exemptions were given by many EU member countries like Germany, Sweden etc in order to encourage refineries to up-grade their facilities earlier than the mandated deadlines. The policies framed so far in the Indian context do not recommend any such incentives for either the refineries or the automobile companies. The market share of ULSD (less than 50-ppm S diesel) increased with duty exemptions announced by the UK government. Figure 4.3 shows that when the duty exemption was increased from 1 pence/l to 3 pence/l, the market share of ULSD increased to almost 100 %.



Source: HM Customs and Excise, *Using the tax system to encourage cleaner fuels: The experience of Ultra-Low Sulphur Diesel*, November 2000

Figure 4.3 Market Penetration of ULSD with fiscal incentives

Gasoline

Gasoline has been recognized as the fuel for speed and is the main fuel for passenger cars and 2 wheelers throughout the world where it is difficult to have diesel engines. Diesel engines are difficult to design in small sizes and have other problems like noise etc, which are a major disadvantage in the segment of vehicles which have been mentioned despite the fact that gasoline engines are less fuel-efficient than the diesel engines of equivalent power.

NO_x and PM are the main pollutants from the diesel engine whereas the emissions from gasoline engines mainly comprise of Hydrocarbons (HC) and Carbon Monoxide (CO). Quality improvements in gasoline have also been mainly focussing on two aspects, one on combustion improvement and the other on reduction of emissions from combustion. The major quality changes that have occurred since the introduction of EURO II gasoline in metros to the proposed changes in the gasoline quality are given in the Table 4.6

Table 4.6 Future Gasoline Specifications

Property	EURO II	EURO III**	EURO IV
Research Octane Number (RON)	90	95	95
Motor Octane Number (MON)	82	85	85
Olefins, vol %	NA	18	18
Aromatics content, vol %	NA	42	35
Sulfur, ppm	500	150	50
Benzene, vol %	1	1	1
Europe Year of Implementation	1998	2000	2005
India year of implementation***	2000	2005	2010

NA- not applicable, no limit for olefins and aromatics content in EURO II.

** RON and MON proposed in the Mashelkar Committee report for the equivalent Bharat III are 91 and 81 respectively which is different from the EURO norms.

*** The year of implementation in India for EURO II and EURO III is proposed by the Mashelkar Committee report.

The important properties of gasoline are divided into the following three aspects:

1. Engine Performance and combustion related
 - Octane Number
2. Emissions Related
 - Aromatics content
 - Olefins content
 - Sulphur

3. Evapourative Emissions related

- Reid Vapour Pressure (RVP)
- Vapour Lock Index (VLI) ($10 \cdot \text{RVP} + 7 \cdot \text{E70}$) (E70 – percentage recovery at 70 Deg C)

Engine Performance and Combustion related

Octane Number is the important property, which affect the engine performance and the combustion in spark ignition engines. Both Research and Motor Octane Number (RON and MON) have been increased significantly in the EURO III standards when compared to the EURO II standards. This increase would require major changes in the components, which comprise the refinery gasoline pool in addition to the new components, which need to be added like MTBE, Ethanol, Iso-Octane (alkylates) to boost the Octane. These components are to be added in order to also compensate for the decrease in Octane Number due to the reduction of Aromatics in the gasoline pool with the specifications reducing the maximum allowable limit for Aromatics in gasoline.

Aromatics and Olefins

Aromatics and Olefins contribute to hydrocarbon and NO_x emissions significantly and also form deposits in the inlet valves and combustion chambers. These are being reduced to lower level in gasoline but not as significantly as in case of US regulations for gasoline. Reducing olefins and aromatics in gasoline as already mentioned above would need the addition of new components to gasoline like MTBE, ethanol, Iso-octane (also called alkylates which are very important and emerging gasoline blend components) etc. This is a cost-intensive quality change and the cost would be significantly high for those refineries having just a Catalytic Reformer, which produce aromatics based gasoline.

The various options available to decrease Aromatics and Olefins in gasoline without causing any Octane loss are given below:

- Blending of ethers like MTBE, TAME
- Blending of Ethanol
- Blending of Alkylates (Iso-Octane)

Sulphur

The sulphur in gasoline deactivates the three-way catalyst that is fitted to reduce the HC, CO and NO_x emissions and increases these emissions with the deactivation in the catalyst. This has been reduced in the various future

regulations to less than 50-ppm. The important point to be noted in this regard is that the processes to reduce sulphur could lead to reduction in Octane also and selection of refinery processes to reduce sulphur without Octane loss is a challenge.

Vapour Pressure

The volatility of gasoline has been under significant scrutiny to address the issue of Evaporative emissions. This is not an issue with the diesel-powered vehicles. To address this issue, the European and US regulations have different summer and winter norms for RVP and VLI. Though there are different VLI norms in India for summer and winter, the issue of RVP increase of gasoline with ethanol blended to the extent of 5 % has not been addressed, now that blending of ethanol in gasoline to the extent of 5 % has been mandated from January 1st, 2003 in the major sugar growing states which is dealt with later. The effect of gasoline quality on Non-Methane Hydrocarbon emissions and NO_x emissions are illustrated in the following two Figures 4.4 and 4.5^{a,b} (Lester Wyborny, 2000)

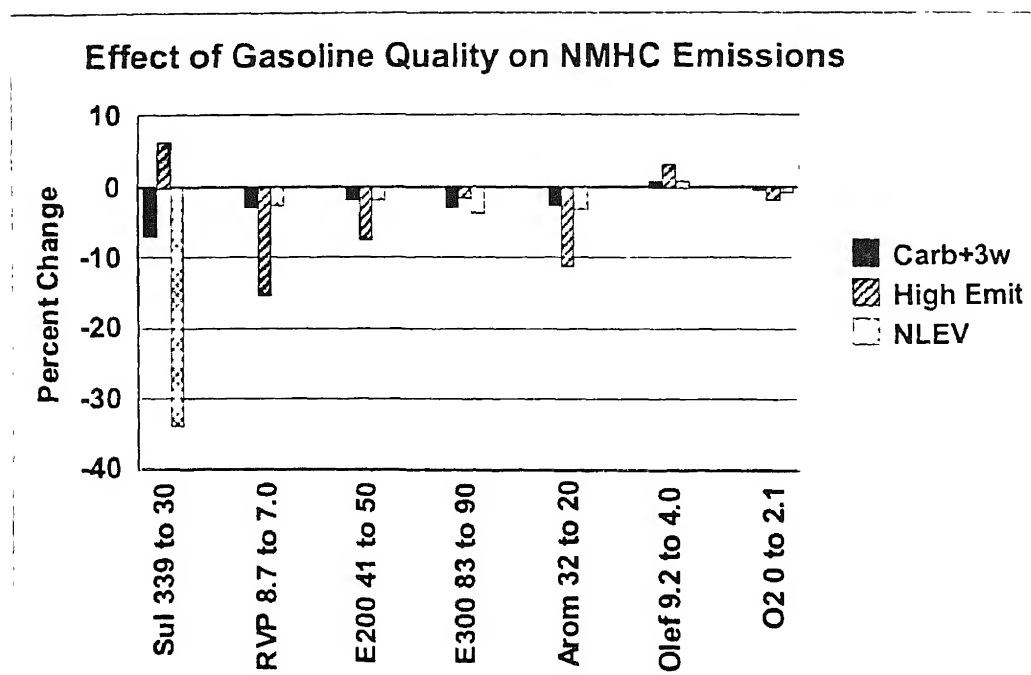


Figure 4.4 Effect of gasoline quality on NMHC emissions

^a CARB – CARB grade gasoline and emission norms, High emit is high emission vehicle, NLEV – National low emitting vehicle programme.

^b RVP in psi, olefins and aromatics in vol % and oxygen in wt %.

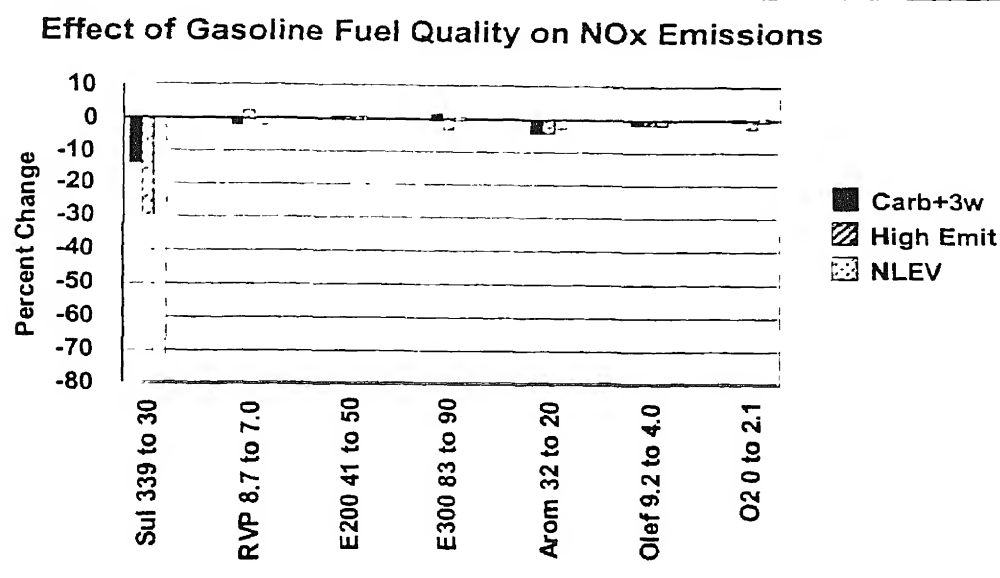


Figure 4.5 Effect of gasoline quality on NO_x emissions

From Figures 4.4 and 4.5 it is clear that for the newer vehicles, sulphur is the most important quality parameter, which affects the emissions from low emitting vehicles. For the high emitting vehicles (older vehicles), the other quality parameters also affect the emissions from gasoline engines.

Gasoline quality improvements have been more significant from emissions reduction viewpoint in the US when compared to other countries in Europe. The Clean Air Act of 1992 mandated certain changes like introduction of minimum oxygen content in gasoline with the focus mainly on the following issues:

- Ground level ozone reduction which is caused by the reaction between the reactive hydrocarbons and NO_x.
- Reduction in toxic air pollutants (TAP) like 1,3 Butadiene, Benzene, formaldehyde etc.
- Carbon Monoxide reduction.

When compared to the baseline emissions of year 1990, there were 2 phases of "Reformulated Gasoline" which were essentially targeting reductions in certain percentages of the above mentioned pollutants. The third phase is also being implemented in certain regions now. The approach to gasoline quality in the US is that the gasoline produced by a refiner should result in reductions in emissions when compared to the 1990 baseline and the % reduction has certain

minimum limits depending upon the region and phase of RFG implemented in that region.

The emissions reduction limits from the 1990 baseline emissions under different phases for summer season are given below in Table 4.7.

Table 4.7 Reformulated Gasoline Norms

Property	Phase 1	Phase 2
Oxygen wt % in gasoline	2.1 min	2.1 min
Toxic Air Pollutants, % Reduction	18.5	21.5
Volatile Organic Compounds, % Reduction	20.8	29.0
Nitrogen Oxides, % Reduction	1.4	6.8

There are some variations of these limits for different regions but the principles are demonstrated in the Table 4.7. The limits are calculated for a particular grade of gasoline by using a spreadsheet model called “Complex Model” for reformulated gasoline to ascertain whether the said gasoline meets the norms as given in Table 4.7.

US Gasoline Quality

The gasoline quality improvements in US have followed a different approach when compared to Europe. In US the local air pollutants in different states have directed the changes in gasoline quality with different states having different norms for gasoline.

California has more stringent specifications for gasoline than that of the reformulated gasoline, which is followed in many states in US with “zero” olefins and very low level of Aromatics in gasoline. (Max allowed only 22 % by volume). To meet the minimum oxygen weight percent in gasoline in US, the following quantities as in Table 4.8 of important oxygenates can be added to gasoline:

Table 4.8 Minimum oxygen content Requirement to meet norms

Oxygenate	Weight % Oxygenate Required
MTBE	11.57
TAME	13.40
ETBE	13.40
Ethanol	6.04

Source. www.eia.doe.gov/emeu/steo/pub/special/mtbe.html, August 10th 2002

As summarized in the Table 4.8, to meet the minimum oxygen content specification of 2.1 wt %, the least quantity is required in case of ethanol. The minimum oxygen content in gasoline of 2-wt % that was mandated after the introduction of the Clean Air Act of 1992 led to the significant increase in the percentage of MTBE blended to gasoline. With a growing perception of the use of MTBE leading to groundwater pollution and its impact (as MTBE is a carcinogen) increasing, refiners in US had to look for other alternatives in order to meet the minimum oxygen content requirement. Many refiners in California were of the view that they could meet the emissions reduction requirements even without the oxygenates. Among the various alternatives that are available to replace MTBE like TAME, ETBE, TBA and ethanol, Ethanol has emerged as the major oxygenate to replace MTBE. The growth of ethanol in US and other countries are discussed in detail later on in this chapter.

There are many refinery processes that are commercialized to help achieving the specifications that are given in Table 4.5, future gasoline specifications. A few of these processes are given below:

- Alkylation, which would produce Iso-Octane (RON = 100). This is the most ideal gasoline component as it will burn completely and since it does not contain any olefins, aromatics etc the emissions would be only carbon dioxide.
- Isomerisation, which produces components like iso-heptane of slightly, lower octane numbers.
- Selective Hydrodesulfurization to reduce sulphur but with minimum Octane loss.

There are refineries in India, namely Bharat Petroleum refinery in Mumbai and Reliance Petroleum refinery in Jamnagar, which would require only minimum modifications to achieve EURO III gasoline quality specifications. But all refineries would require significant modifications in order to meet EURO IV modifications as some additional processing facilities will have to be added.

Review of Policies

There have been interventions in the policies related to the gasoline quality changes. The Supreme Court mandated the introduction of EURO II gasoline, which contains less than 1% benzene by volume and less than 500-ppm Sulphur. The Mashelkar Committee has suggested the future roadmap for change of gasoline quality.

The schedule for implementing these changes has been given by the Mashelkar Committee, which also lists the fiscal incentives that would be required for refineries for implementing these changes. The report chalks out a roadmap for introduction of EURO III in the entire country by 2010 and EURO IV standards in metros and other select cities by 2010. But, it also has to be noted that the report does not talk of providing any incentives to those refineries, which upgrade their facilities before the mandated deadlines. This means that there is no possibility of refineries upgrading facilities before mandating deadlines unless there are new entrants in the oil-marketing sector and the competition induced in marketing drives refineries to change to safeguard market share thereby survival. It is also important to note some recent announcements made with regard to blending ethanol in gasoline, and the impact on gasoline quality and price which would be dealt with in detail later on in this section.

Additives in Conventional Fuels (Diesel and Gasoline)

In addition to these major quality changes, oil-marketing companies would add performance improving additive packages to both diesel and gasoline. These additives will increasingly become important with the “branding” of diesel and gasoline after deregulation of the oil marketing. These packages would mainly comprise of the following components:

Common additives for gasoline and diesel

- Detergents to clean the intake valve of deposits.
- Antioxidants to ensure no deterioration over a period of time.

Additives for gasoline

- Corrosion inhibitors etc.
- Octane improvers like MMT or Ferrocene

Additives for diesel

- Combustion Improvers like Platinum
- Cetane Improvers

These additive packages as claimed would help in reducing maintenance of the engine and also help in improving efficiency of the engines. The benefits of these packages on engine performance and emissions cannot be generalized, as the packages used by different companies could be different.

In the context of effect to the engine and after-treatment devices, these issues will have to be studied in detail. There are some metallic additives like MMT marketed by Ethyl Corporation, which could have negative impact on the engine in the long term and could also result in harmful emissions. Some of the

additives could give the refineries a low cost option to meet a particular property like Octane Number of gasoline etc but all aspects of such a step are often not a priority for the oil companies. The automobile companies should hence study the issue of additives in fuels in great detail both in terms of the emissions and engine impact.

Branding of fuels by oil-companies will be a significant phenomenon, which will be driven by the competition in the marketing sector. Branded gasoline like Speed of BPCL, Premium of IOC etc have already been launched. These branded fuels constitute significant proportion of a detergent to help remove the deposits on combustion chambers and injectors. By keeping the injectors and the combustion chambers clean, fuel injection and combustion are more efficient, thereby ensuring better fuel efficiency and also lower maintenance of the engine. In this context it is important to note that multifunctional additives (MFA) whose main constituent is the detergent is already mandated since three years and the gasoline is supposed to be blended with these additives. This mandate is not enforced properly.

Automobile companies need to take a proactive role in identifying the major changes between these branded fuels and normal fuels and understand the impact on the engines and other related equipment.

Gasohol - Ethanol blended gasoline

Ethanol, both as a neat fuel as well as a blend component came into sharp focus during the Oil Shock of 1973 when Brazil launched a programme called the "Proalcool" programme. Another important reason for the growth of ethanol was for reducing the CO and HC emissions from gasoline. Ethanol which is an oxygenate ensures better combustion as it provides for oxygen with the fuel itself making the fuel a leaner mixture.

This programme in Brazil was launched giving lot of subsidies to the sugarcane growers' (www.platts.com, August 5th 2002). Due to this programme, there was a significant increase in the percentage of ethanol used both as a neat fuel as well as in gasoline as a blend component. Now, as world's largest ethanol producer, Brazil uses nearly 4 million tonnes of ethanol. Approximately 40 % of the cars in Brazil run on 100 % ethanol fuel and the other 60 % use a 22 % ethanol – 78 % gasoline blend. In the late eighties the ethanol consumption has remained stagnant due to the withdrawal of the subsidies that were available. The growth of neat ethanol cars is almost flat, as the Brazilian government has withdrawn some of the subsidies that were available with neat ethanol.

The major country experiences are briefly discussed below with some lessons for the Indian context and also the development contemplated in the use of this fuel in India. The latest policy decisions taken in this direction are also summarised in this section along with the concerns that need to be addressed in India with regard to the use of this fuel.

Europe

The European Commission published an action plan and two directive proposals in November 2001 to encourage use of biofuels in the transport sector. The action plan and the two directives are given below:

- Reduce the European Union's (EU) dependence on external oil supply.
- Contribute to EU greenhouse gas emission reduction targets as agreed in the Kyoto Protocol.
- Meet the objective of substituting 20 % of diesel and gasoline fuels by alternative fuels in the road sector by 2020.

The first directive calls for an establishment of a minimum level of biofuels as a proportion of fuels sold from 2005, starting at 2 % and reaching 5.75 % of fuels sold in 2010. It is though not clear as to whether these directives are indicative or mandatory.

The second directive deals with tax issues, seeking to give EU member states the option of offering tax breaks on pure or blended biofuels used in either heating or motor fuel. But the time frame for introduction of these breaks is not clear.

It is also to be noted that more than ethanol, bio-diesel is the biofuel, which has gained enough ground in Europe unlike Brazil or US where ethanol is the major biofuel.

In addition to the EU issuing certain directives, several countries individually have undertaken many projects to increase the use of biofuels. In May 2002 France and Italy received European Commission's clearance for biofuel tax breaks. As already stated Europe's focus has been mainly on bio-diesel rather than ethanol. The total bio-diesel production in Europe was around 7 lakh tonnes whereas the total ethanol production was only about 2 lakh tonnes. (Source: Platts, www.platts.com, August 5th 2002)

The bio-diesel part will be discussed in detail in the bio-diesel portion of the chapter.

It is also to be noted that ethanol is not used directly in some EU member countries like France. Ethanol is converted into ether called Ethyl Tertiary Methyl Ether (ETBE).

US

With the implementation of the Energy Policy Act (1992), which was aimed at the reducing US dependence on imported petroleum by encouraging use of alternate fuels for certain vehicle fleets such as federal fleets, state government fleets and private fleets. The act required fleets to buy a certain number of alternate fuel vehicles (AFVs) with every new purchase depending upon whether it is a state, federal or private fleet. Increasing AFV purchases under this act, along with a phase out of MTBE made a significant impact on the biofuels market of which ethanol is a major component. This was aimed at increasing the penetration of AFVs, which would also help introduction of new technologies for reducing emissions.

Ethanol derived from grain accounts for almost all of current US biofuel production. The use of ethanol has been boosted by the ban on MTBE, which is being enforced in all states in US. The Clean Air Act of 1990 mandated the use of oxygenated fuel in areas, which had wintertime carbon monoxide emissions and also to reduce the ground level ozone formation due to the photochemical reaction between some reactive hydrocarbon emissions and NO_x emissions. The blending of ethanol or MTBE gave oxygen along with the fuel itself, which helped reduce the hydrocarbon emissions. The gasoline that was mandated in these areas was called "Reformulated Gasoline" as discussed in the earlier section. The US EPA points out that about 300 MMT of pollution has been eliminated nation-wide since the RFG program has been implemented.

The Energy Policy Act presented before the Senate in June 2002 proposes to remove the oxygenated gasoline mandate and introduce a minimum renewable fuel standard for all transport fuels with a roadmap for increasing the use of renewable fuels to three times than what their current levels of usage are. This implies that there would be a significant increase in the percentage of ethanol being blended in gasoline.

Another major impetus to the increased use of ethanol in US is to decrease the dependence on foreign oil. Twenty-four gallons of ethanol is equivalent to one barrel of oil. The Renewable Fuel Association of US points out that tripling ethanol consumption could replace Iraqi imports totally.

The main concerns though in increasing the use of ethanol is the price of ethanol and its subsequent effect on the price of gasoline. Currently there is a 54

cents per gallon excise exemption on ethanol, which makes it competitive to gasoline. The competitiveness of ethanol as a neat and a blended fuel would be difficult in case there is no such fiscal incentives in US.

Asia Pacific Overview

Platts points out that the oil production in Asia Pacific will decline in the next 5 – 10 years as key oil fields reach maturity with not many major new finds to replace them. Developing gas markets and high oil prices may hold some incentive for exploration but new oil prospects in the region are dim. Lower production from Asia means that there would be increasing dependence on imports from other regions like the Middle East, Africa and Latin America to supplement its own oil supply. Alternatively, using alternatives like biofuels are seen as a substitute for oil products. The major countries in this region where the share of biofuels has increased are Australia, China, Thailand and India especially the use of ethanol mainly to replace significant fossil fuel based energy use and to reduce reliance on oil imports. (www.platts.com/biofuels, August 5th 2002)

Australia

The Australian government in its 2002 budget decided to reallocate about 2.8 MM\$ over 2002-2004 from the Greenhouse Gas Abatement Programme to fund a study addressing the market barriers to the uptake of biofuels. The study will assess the merits of nationally mandated minimum biofuel standards for the transport sector similar to the policy proposed in US. They have also undertaken a study to determine appropriate standards for ethanol blend fuels, following up on concerns of some vehicle manufacturers about operational and mechanical problems. This is a very important aspect, which needs to be analyzed as far as the biofuels are concerned. The Australian government intends to use this study to help decide on options for implementing its election commitment to support increased production of biofuels in Australia. It is aiming to develop a broad strategy to increase the production of both bio-diesel and ethanol to about 350 million liters by 2010. Individual state governments in Australia like Queensland State have also come out in strong support of developing an ethanol industry in the state to reduce dependence on fossil fuels and more importantly creating a local demand for sugar cane and grain. This will result in increased farm incomes leading to overall economic growth.

China

China sees ethanol as an opportunity to utilize grain surpluses more efficiently and to also reduce the amount of oil exports. China is promoting ethanol-based fuel on a trial basis in five cities in the Central and Northeastern provinces. The move not only cuts domestic petroleum consumption and pollution through fossil fuel use, but also creates a new market for China's surplus grain output. There are plans to promote use of ethanol-based fuel to big cities in the coming years and there is full political support for this programme with the involvement of key economic departments also in this project.

Thailand

The focus in Thailand also has been on increasing self-reliance and reduce oil imports for meeting energy demands. Many steps have been taken to promote the use of biofuels like excise tax exemption for ethanol and an income tax waiver for investors for first eight years and only 50 % income tax for the next 5 years. These incentives have already led to the approval of five projects with 8 lakh liters per day production. The ethanol is sold as a 10 % blend with gasoline. The incentives given for ethanol would make ethanol-blended gasoline cheaper than standard gasoline. Ethanol is produced in Thailand mainly from molasses and cassava. It has surpluses of both these products and if they are used to produce ethanol then the Thai government would save significantly as it otherwise has to support farmers coping with low cassava prices. Thailand also proposes to replace the MTBE that is blended in gasoline here as an Octane boosting additive by ethanol in order to save foreign exchange.

India

In India ethanol as a blend component for gasoline is in focus since 1997 when there was a private members bill placed in Parliament. In 2001 three pilot demonstration projects for distribution of ethanol at 5 % level in gasoline was launched. (In two places in Maharashtra and one place in Uttar Pradesh.) India is heavily dependent on oil imports with the import bill as high as \$ 17.5 billion last year and this programme is primarily being pursued from aspect of reducing oil imports. On the other side the sugar and distillery industry would gain immensely in terms of higher byproduct realizations and higher capacity utilization as the sugar industry is facing a crisis of excess sugar production and reduced domestic demand which is leading to lower realisation exports. There are some fears on possible increase in prices of molasses, which is the main feedstock for production of ethanol in case ethanol demand increases.

Policy Developments

The government is determined to push ahead with increasing the use of ethanol as an alternative fuel with the recent announcements mandating blending of ethanol up-to 5 % in 9 states (Andhra Pradesh, Karnataka, Maharashtra, Tamilnadu, Punjab, Haryana, Uttar Pradesh, Gujarat, Goa) and 4 Union Territories (excluding Delhi) from 1st January 2003 which will later on be mandated for the entire country. The percentage of ethanol blended in the three pilot projects will be increased to 10 % to further increase the mandated blend percentage to 10 % at a later date. This policy has not been framed in a co-ordinated fashion in terms of the time frame for changes in fuel specifications as recommended by the Mashelkar Committee report.

Issues and Concerns

The economic aspects of such a decision have not been studied, thereby the costs of such a decision are yet to be evaluated by the government. While there are many similarities between Brazil and India in terms of their sugarcane production, there are many factors, which are different and should be taken note of. The issue of subsidies, which led to the growth of ethanol in Brazil and the growth of the oil industry in Brazil with ethanol as a major fuel, are situations very different from the Indian scenario. It is also to be noted that some refineries in India already produce oxygenates like MTBE, TAME in significant quantities and mandating ethanol to the extent of 5 % will directly affect these refineries.

Change in Refinery end Gasoline standards due to ethanol blending in gasoline

There are some technical issues on the automobile front which are being addressed but another important technical aspect of the introduction of gasohol is the effect it would have on the refinery gasoline blending schemes. Ethanol blends have a higher Reid Vapour Pressure (RVP) when blended in gasoline, which will lead to limitations on the base refinery gasoline blends. Targeting lower RVP levels for gasoline at the refinery end would be at an additional cost which also should be evaluated. There have been studies done by the US Environmental Protection Agency (US EPA) and CARB to evaluate this cost to the refineries. Similar studies should be conducted in the Indian context to ascertain the “real” cost of ethanol. There have been changes made in the

refinery end gasoline quality in US in order to account for the increase in the RVP after blending ethanol to the extent of 5 – 10 %.

The issues that are of concern to the quality and price of gasohol are summarised below:

- Volatility of gasoline which is blended with ethanol and the resultant evaporative emissions effect and also general engine performance needs to be studied. Though there are some studies on the engine emissions being conducted by IOC (R&D), these areas have not received due attention.
- There is a need to change the RVP standard of gasoline produced at the refinery end in order to ensure that after the blending of ethanol at the depot end, the final products meets the gasoline quality standards. Also there is need to look at the summer specifications of gasoline specifically from the RVP point of view.
- Corrosion of automobile parts has also been a concern with the use of gasohol and needs attention.
- There are also some studies, which indicate the lowering of stability of gasoline blended with ethanol. This could lead to deposit formation on inlet valves etc, which again would require studies to determine these effects.
- The gasoline prices could increase with ethanol blending being made mandatory to start with in 9 states and 4 Union Territories from January 1st 2003.

Bio-diesel

Bio-diesel is esterified oil either from edible oil sources or non-edible oil sources. The base oils used for production of bio-diesel are different in different countries and thereby the properties of bio-diesel will also vary based on the source of oil. The major properties are very similar to that of conventional diesel in terms of important properties like Cetane Number etc. This enables their use with little or no modifications to the current design of engines. They also have some properties, which gives them a distinct advantage over conventional diesel, though when compared to conventional diesel their regulated emissions are not significantly lower. The most important advantage is that they are “zero” sulfur diesels which enables the use of all the advanced after treatment devices, which are extremely sensitive to sulfur in diesel thereby ensuring low level of emissions. The measures taken in different countries to increase the use of bio-diesel are given below.

Europe

As already mentioned in the portion on ethanol, use of bio-diesel in Europe is significantly more than the use of ethanol unlike other countries where the reverse is true. Several countries have taken their own steps to increase the use of bio-diesel. The EU has allowed Italy to charge excise duties at reduced rates on fuels containing bio-diesel until June 2004. This proposal applies to mixtures containing 5 to 25 % bio-diesel. Germany also decided on a biofuels exception from the national ecotax on energy, which is levied on other fuels thereby encouraging the use of bio-diesel.

Contrary to the US, bio-diesel is the dominating biofuel as already mentioned in the earlier section with France, Germany, Italy, Austria and Belgium being the top producers of bio-diesel. The German production of bio-diesel is increasing at the maximum rate among the countries mentioned and in 2000 it grew by more than 30 %.

The only bottleneck to the growth of bio-diesel has been the cost of bio-diesel when compared to conventional diesel. EU estimates the cost of bio-diesel to be almost double the cost of conventional diesel after adding the refinery costs of upgrading diesel is included. Some countries like Germany, Austria and Sweden use 100 % bio-diesel in specific fleets. In France, bio-diesel is blended at 30 % in captive fleets and also used in blends of 5 % in normal diesel fuel. In Italy, it is blended at 5 % in normal diesel fuel.

US

In US as of September 2001, there were over 100 major vehicle fleets using bio-diesel. Credits were given to those fleet owners who used bio-diesel with more credits being given to those fleet owners using higher percentage of bio-diesel. It is also to be noted that the cost of bio-diesel is higher than regular diesel. There are many initiatives taken by the government to lower the production costs of bio-fuels thereby ensuring lower market prices to boost the demand of bio-diesel.

Many organizations are increasingly using bio-diesel in their fleets. Bio-diesel meets the EPA's phase-wise Health Effects requirement, under the Clean Air Act of 1990 as its emissions are non-toxic and pose very little health risk. These health effect requirements are framed to reduce the various unregulated emissions based on their epidemiological effects. Also, the standardisation of bio-diesel fuel composition by the American Society of Testing and Materials (ASTM), is also a plus in pushing bio-diesel as an alternative fuel of choice in the US market.

Asia Pacific Overview

The focus in Asia Pacific countries has been mainly on ethanol rather than on bio-diesel with many Asian countries having significant sugarcane production. Australia is the only country where specific efforts have been put to increase the production of bio-diesel and also reduce the cost of production of bio-diesel. Considerable investments have been made in bio-diesel production facilities. The focus in other countries has been mainly on ethanol blended gasoline only and currently bio-diesel is still at a very nascent stage in terms of introduction in the market.

India

In India the development of bio-diesel is at a relatively nascent stage. The potential sources of bio-diesel oil seeds have been identified and also some experiments on some of the trans-esterified oil from these seeds are underway. Indian Oil Corporation is undertaking emission studies in addition to the development in non-edible oil seeds production undertaken by the Ministry of Agriculture. There are major issues of cost of bio-diesel, which have not been studied in detail but are very important for the growth of bio-diesel as an alternate fuel. The policy as far as use of bio-diesel is also not yet clear, i.e., uses of bio-diesel as a neat fuel or in blended form along with conventional diesel. This would also be very important to understand the effect on the engines. Some indications are available from the Ministry of Rural Development on the proposed roadmap of development of this fuel on a massive scale throughout the country. The major crop identified for this purpose is *Jatropha* oil seed, which is a non-edible oil seed and is very easy to grow and has a very short cycle of growth when compared to some other non-edible oil seeds. There is some development of *Karanja* oil seeds in Karnataka where the esterified oil is being used for power generation and in diesel generator sets. An important component, which is required for the production of bio-diesel, is either methanol or ethanol for the trans-esterification reaction. In India, ethanol could be used for this process, as there is a surplus of ethanol in the country. The Mashelkar Committee report lists a few identified oil seeds for bio-diesel production. The important properties of transesterified oils, which are relevant in the Indian context, are given below: (will be given as and when they are available).

Biofuels will receive increasing importance in the years to come as the focus on reducing CO₂ emissions increases with many countries promoting biofuels mainly from this viewpoint. Also since the growth of biofuels would have a

positive impact on the agricultural incomes and also reduce wastage of agricultural land, these would be in good focus in the years to come.

Gaseous Fuels

The main gaseous fuels, which are discussed in this section, are LPG and CNG. These two gaseous fuels are increasingly in focus with particulate emissions from diesel engines an area of major concern and alternate fuels to tackle this problem are being studied. While the use of CNG for heavy-duty applications are more established than that of LPG, the supply / demand constraints of a particular country determine the predominant choice between these fuels.

LPG

Liquefied petroleum Gas (LPG) is a product obtained during the petroleum refining process and during natural gas processing. LPG is a combination of hydrocarbons having 3 and 4 carbon atoms with the main components of LPG in India given below:

- Propane
- Propylene
- N-Butane
- Iso-Butane
- Butenes
- Butadienes

LPG presents a useful combination of combustion and storage properties among the gaseous fuels. It is a gas at normal temperatures and thus has the advantage of mixing with air in any proportion therefore not posing any cold start problem. The lean combustion limit of LPG-air mixtures is also considerably higher than gasoline allowing use of lean-burn calibrations, which increase efficiency and also reduce emissions. LPG will emit almost “zero” particulates when burnt in spark ignition engines. NO_x emissions are not as low of CNG engines as under very lean conditions CNG is supposed to burn better than LPG.

Factors influencing growth of Auto LPG internationally

LPG, mainly propane and butane has seen tremendous growth in US and many European countries due to many factors. Some of them are listed below:

1. In US, LPG especially butane which used to be blended in gasoline had to be taken out of gasoline due to reduction in the Reid Vapour Pressure limit of

gasoline in order to reduce evaporative emissions from automobiles. That led to lot of butane product without any proper market and its development as an autofuel itself.

2. Unlike in India, where LPG is a major domestic fuel, LPG in major developed countries is used mainly as a petrochemical feedstock. To ensure proper market for LPG, which is an important by-product of the refining process, the use of LPG as an autofuel has developed. The main European countries where LPG is a major autofuel are The Netherlands, Italy and in some cities in US.
3. LPG has also developed where gaseous fuel use for automobiles has been encouraged and the infrastructure required for distribution of CNG is not available or is prohibitively costly.
4. The main application of LPG has been in the light-duty applications rather than the heavy-duty applications in most countries bit for some cities in the US where propane-fuelled.

Development of Auto LPG in India

In the Indian context there are issues on quality of auto LPG and also availability of auto LPG which have not been addressed in detail and are very important in the context of their increasing use. Also in the Indian context LPG is being projected as an alternative to CNG in heavy-duty applications like buses etc with the latest Supreme Court verdict of 5th April 2002 recognizing LPG as the only clean “unadulterable” other than CNG. It is important to note that encouraging use of LPG as an auto fuel would affect the profitability of the refineries. The additional costs to the refining industry of promoting auto LPG has been summarized in the Mashelkar Committee report. The growth of LPG as an auto fuel would be mainly in the short term when the refineries do still not produce the conventional fuels of EURO III and EURO IV quality. There are no major studies on LPG for heavy-duty applications in India, though there are some studies done internationally on use of LPG for heavy-duty applications. Some studies have reported that LPG heavy-duty engines have durability problems with stoichiometric air fuel ratios. The emissions performance of lean-burn engines was observed better than that of the stoichiometric engines. (Goto, 1999) The current focus on LPG by major oil marketing companies on auto LPG can be seen as an effort to project alternatives for CNG. The increasing use of CNG would affect the profitability of oil-marketing companies and the increasing focus on LPG can be seen as an effort to check the decline. Some

rough estimates of the losses are available but no detailed study on the same has been done.

Auto LPG Quality in India – Issues and Concerns

The important specifications of AutoLPG in India are given below in Table 4.9:

Table 4.9 Auto LPG specifications

Property	Limits
RVP, KPA (max)	520
95 %Volatility (Max), Deg C	2
Sulphur (Max) PPM	150
Mercaptans (Max) PPM	20
Research Octane Number (Min)*	88
1,3 butadiene, % vol max*	0.5
C5 and above, % vol max	2

* The only parameters, which are different from the domestic LPG which is used for cooking purposes.

There are many issues, which need to be looked at in perspective. One of the most important issues that needs to be noted by LPG vehicle manufacturers is the composition of LPG that will be used in automobiles. There is an automotive LPG specification that has been laid down by Bureau of Indian Standards (BIS) but it is not very different from the domestic LPG specification. Specifically there is no minimum limit on Propane content in the LPG, which is the best component among the various constituents of LPG. Of the hydrocarbons commonly included in LPG, propane has the best antiknock property compared to gasoline. The antiknock property of other components in LPG is inferior to propane and gasoline, which raises an important concern on the design parameters to be used for designing spark ignition LPG engines. For example, the common components, which are a part of LPG, are propylene, butanes and butenes. With propylene, butenes and butadienes in LPG, there would be significant reactive hydrocarbon and NO_x emissions as they are olefinic components and have similar effect as olefins in gasoline. In this context many countries have hence notified standards, which mandate the use of neat propane only. It is also important to note that propane will not offer any specific advantage as far as its higher octane number is concerned if the existing gasoline engine design is just modified to use LPG. In Europe a minimum Motor Octane Number of 89 for LPG has been mandated in order to ensure satisfactory operation on LPG of engines designed for European premium leaded gasoline

having a MON of 87. The higher MON was mandated in order to be able for use in older engines also. In US LPG is mandated to be “neat” propane. The Table 4.10 gives the propane and propene content in LPG in different countries. The auto LPG quality in India does not specify any minimum quantity of propane in LPG as already mentioned before (CONCAWE, 1995).

Table 4.10 Propane and Propene content of LPG in different Countries

Country	Vol % in LPG
Belgium	40 - 60
France	20 - 50
Germany	100
Netherlands	30 - 70
US	98 - 100

In India LPG is mainly produced in refineries and there is one plant, which recovers LPG from natural gas in Hazira, Gujarat. In refineries, LPG is produced from many processes. LPG is a part of the crude oil and its percentage in crude oil varies between different crude oils. LPG in crude oil mainly consists of propane and butane (both normal-butane and iso-butane, iso-butane has the higher octane number of the two). Significant quantities of LPG in India are produced from secondary refining processes like from the Fluidized Catalytic Cracking Unit. LPG from these secondary-processing units would be very “olefinic” (components like propylene, butenes and butadienes) in nature due to the nature of these processes. A critical unregulated pollutant in the US is 1,3-butadiene. These emissions are very high when LPG is used as a fuel. It is also to be noted that refineries have been opposing introduction of a max “olefins” content in LPG fuel quality standard in view of the processes being used for production of LPG and the economic impact that it would have on the price of LPG. Additional facilities would have to be installed in order to convert these “olefinic” LPG components to propane and butane alone. India is not self sufficient in LPG unlike the other petroleum products like gasoline and diesel where there is a surplus capacity in terms of refining capacity. In the context the use of LPG as an autofuel, the availability of LPG will thus be a major issue. The Mashelkar Committee report also points out a deficit on the LPG supply scenario assuming 10 % gasoline demand substitution by auto LPG after 2 years and 25 % after 5 years. The deficit is 0.8 MMT (metric million tonnes) in 2002-03, 2.75 MMT in 2004-05 and 5.88 MMT in 2006-07. On the infrastructure

front also there are issues to be addressed which will be dealt with in detail in the section on fuel related infrastructure.

Safety Issues related to Auto LPG

On the safety of using LPG as an autofuel, there are some studies (CONCAWE, 1995), which point out that using LPG poses a greater safety risk than CNG. Unlike natural gas, LPG vapours are heavier than air and any leaks of LPG will pool at the ground level. But the flammability limits of LPG are also as broad as the limits for natural gas. There are some countries in Europe where LPG vehicles are not allowed to be parked in enclosed places due to this enhanced risk factor and increase the safety levels due to the use of LPG as a fuel. There are very strict norms in place for designing LPG storage cylinders and other safety related accessories for automobiles including in India.

Advantageous Position of Auto LPG in the Indian Context

One of the major advantages that auto LPG will have over gasoline in the Indian context is the price advantage over gasoline. Today the high level of taxation on gasoline is used to provide the subsidy on domestic kerosene and LPG. So, auto LPG without any subsidy and at market prices at current levels of taxation on LPG will be cheaper on a Rs/km basis when compared to gasoline (LPG priced at about 18.5 Rs/l when compared to gasoline which is priced at about 31 Rs/l). This will be dealt with in detail in the section on relative costs of different fuels and the factors affecting the costs of different fuels.

CNG

With the growing focus on particulate emissions from heavy-duty diesel engine applications and with conventional fuel application requiring significant time for implementation by refineries, CNG has emerged as an alternative to reduce particulate emissions in the short term. There are issues on the emissions performance, availability and infrastructure-related issues, which are being debated and are very crucial for development of CNG as an alternate fuel in the Indian context.

Advantages of CNG

Natural gas generally has excellent antiknock property, which is best suited for spark ignition engines and over the years has emerged as a viable alternative for gasoline in passenger cars. Due to the excellent antiknock property, engines designed specifically for natural gas fuel can use higher compression ratios than

gasoline engines with a consequent improvement in efficiency and power output. The antiknock performance of natural gas is best for pure methane or methane / inert gas mixtures, and declines somewhat with increasing concentrations of non-methane hydrocarbons.

As mentioned before emissions from natural gas and LPG vehicles are generally lower than those from gasoline vehicles at the same level of engine technology.

CNG – Need for Quality Standards in India

Wobbe Index

An important aspect of natural gas from an emissions viewpoint is the composition of natural gas in terms of the methane and ethane content. This is not standardized in India and the composition of natural gas varies in different places in the country based on the source of natural gas and the downstream processing that the natural gas is subjected to after production. In other countries, the Wobbe Index ((ratio of volumetric heating value to the square root of the specific gravity of the gas) is standardized which ensures that there is some degree of consistency as far as natural gas quality is concerned. The Wobbe Index would provide a useful means to also fix the optimum air-fuel ratios in order to achieve best efficiency and power output. In the Indian context automobile companies should work towards standardisation of the CNG quality by having a specification for the Wobbe Index, which would help in maintaining a particular level of engine performance. This property is also important for fuel metering which is an important aspect for maintaining accurate air fuel ratios based on the composition of the fuel. Pure Methane has a Wobbe Index of 50.61 MJ/m³. The automobile companies should ask for standardisation using indices like the Wobbe Index for the quality of CNG, which currently has no standard other than the minimum pressure requirement.

Molecular Composition of CNG

Modern, stoichiometric spark ignition engines with closed loop control of the air-fuel ratios are able to compensate for reasonable variations in the Wobbe Index. For engine control systems without air-fuel ratio feedback, such as those used in heavy-duty engines, variations in fuel composition can present a significant problem- possibly resulting either in poor engine performance (due to too lean a mixture) or engine damage due to overheating (with the mixture too rich).

Methane Number

Another parameter, which is used to determine the combustion behaviour of CNG, is the methane number (MN), which is similar to the Octane Number of gasoline. Just like Iso-Octane has an Octane Number of 100 and n-heptane has an Octane Number of 0, pure Methane has a Methane Number of 100 and Hydrogen has a Methane Number of zero. Study by the South West Research Institute conclude that the Motor Octane Number (MON) and Methane Number are correlated and had the following best-fit relationship with R^2 greater than 0.95 (CONCAWE, 1995)

$$\text{MON} = 0.679 \cdot \text{MN} + 72.32$$

$$\text{MN} = 1.445 \cdot \text{MON} - 103.42$$

Typical CNG Specifications

There are currently no specifications for CNG sold in various cities in India. The following parameters need to be standardised in order to ensure low emissions from CNG engines.

Table 4.11 CNG Typical Specifications

Property and units	Specification	EPA In Use CNG	Suggested Typical Value
Methane Content, vol %	Minimum	89	89
Ethane Content, vol %	Maximum	4.5	4.5
Wobbe index, btu/scf	Minimum	NA	1350
Wobbe index, mj/m ³	Minimum	NA	50
Methane Number	Minimum	NA	95
Inert gases, vol %	Maximum	4.0	4.0

NA – Not available.

The typical values are suggested specifications of CNG based on the fact that CNG should have maximum methane content and ensure that the air/fuel metering systems function and achieve high combustion efficiency as per the design.

This is required in order to ensure that the performance observed at the test level is observed even during normal operation of vehicles, which is particularly important in the context of heavy-duty applications. This will not be much of an issue after the start of getting CNG from imported LNG, which consists of almost 99 % methane and has a high and a constant Wobbe Index.

CNG use as Transport Fuel- Other Issues

In India, the major issue as far as CNG is concerned is its availability and also the market price without any subsidies / exemptions etc. The oil and gas marketing is now free from government controls since April 1st 2002. This will allow the gas marketing companies like GAIL to price gas at market determined levels, though the government continues to control the pricing of natural gas as GAIL is government controlled. The determinant of the gas price will be the relative price when compared to LNG and there is pressure on companies like GAIL to price domestic natural gas at levels of LNG price in order for LNG to be competitive for all sectors.

Development of natural gas as an automotive alternate fuel has taken place in different countries due to many reasons and conditions. Among the major countries where natural gas has developed as a viable alternative fuel, infrastructure development and abundance of domestic natural gas supply for supply of natural gas has been the major factor towards development of the natural gas markets. Infrastructure for supply of natural gas mainly consists of cross-country pipelines, compressors and gas-dispensing stations. Some of the Far Eastern countries have significantly increased use of CNG in vehicles with the significant growth of LNG imports and the related infrastructure. In countries like Japan and South Korea, the major source of natural gas is from LNG imports. In this context it is pertinent to note that LNG comprises more than 25 % of Japan's energy supply for power production when compared to only 23 % of energy supply from petroleum. This is in striking contrast to many developing countries like India where the major energy source has been petroleum followed by coal and gas comprising a very small source of energy. In these countries the LNG import infrastructure has seen significant development over the past two decades with Japan emerging as one of the biggest LNG importers in the world. With domestic natural gas resources depleting and expected to last only till about 2010, imported LNG will be the only source of natural gas and hence will be the determinant of the natural gas prices in the long term. Another important inference that can be drawn from the growth of natural gas in various countries is the abundance of domestic sources of natural gas leading to development of the markets, specifically in case of countries like Argentina, Venezuela, Egypt etc. It is also to be noted that whilst the initial development of natural gas vehicles was in the passenger car segment, recent growth has been more significant in the heavy-duty applications due to the

growing concern of particulate matter emissions from diesel engines as already pointed out earlier.

One factor, which is to be noted with regard to the growth of CNG in heavy-duty applications, is the relative costs of the technology and fuel when compared to the conventional fuels and their technologies. The current cost difference could be a major discouraging factor in the scenario of CNG not being mandated (unlike in Delhi where CNG has been mandated as the fuel for city buses) and equivalent technology in terms of emissions is available from conventional fuels like diesel and petrol. These issues are discussed in detail in the section on fuel costs and infrastructure issues.

Institutional Mechanisms Required and Enforcement

The major changes discussed in this chapter both in case of the conventional fuels and alternate fuels require enforcement in the following areas to ensure that the emission benefits identified are achieved. The major issues, which are important in this regard, are listed below:

- Control over the quality of gasoline and diesel with specific enforcement to ensure that adulteration of fuels does not take place. This will also have to be checked by way of pricing which is possible in the long term (5-7 years), but in the short term, enforcement by way of checks from oil companies, government agencies and voluntary organizations would be very important to achieve the emission targets on the ground.
- Strict adherence to safety norms in case of gaseous fuels like CNG and LPG at the various levels of transmission, distribution, vehicle conversion kits, fuel storage in vehicles etc. This will be the most important enforcement issue with regard to the use of gaseous fuels. As pointed out earlier in the chapter, the issue of quality of these gaseous fuels is also important from the aspect of enforcement.

Conclusions

The summary of the various issues discussed and raised in the chapter are given below:

- The roadmap for change of diesel and gasoline fuel quality will most likely be broadly based mainly on the recommendations of the Mashelkar Committee report. With the intervention from courts the deadlines might undergo significant changes, but the philosophy of change would remain the same.
- As pointed out, competition in the sector of oil marketing will be another important driving factor for change in fuel quality in the country.

- The absence of any concrete incentives for oil companies will mean that the introduction of the fuels meeting certain quality norms will not be done before the mandated deadlines unless competition induced in the oil marketing sector drives the change with the entry of many new private players.
- The technical issues concerning the use of additives in fuels needs extensive study from the automobile sector with the introduction of “branded” fuels in the country due to the de-regulation in the oil-marketing sector.
- The introduction of ethanol mandate in India from Jan 1st 2003 starting with the mandate in 9 states and 4 Union territories could have a significant influence on the price of gasoline if sufficient reduction in taxation levels of gasoline are not announced.
- Technical issues arising out of the ethanol blending mandate such as volatility of gasoline, which would influence the evaporative emissions from gasoline powered vehicles should be given lot of attention from both automobile and oil-marketing companies.
- Automobile companies should ask for review of standards of diesel and gasoline with the introduction of ethanol and bio-diesel as blend stocks for these fuels.
- Bio-diesel is still in the development phase and should be a focus area for companies whose core competence is the diesel fuel based technologies and build synergies to get initial advantage in this sector.
- Policy initiatives on the introduction of bio-diesel as a blend component in the conventional diesel are being taken and this area will see development in the next few years.
- The standards of current auto LPG quality in India could actually lead to more toxic unregulated pollutants, which need to be examined in detail.
- There is currently no standard for CNG quality in the country other than some individual informal agreements between the gas supplier and the transport operators. There should be pressure from the automobile companies to standardise the quality of CNG similar to the standards that are in place for liquid fuels to ensure that the emissions from CNG vehicles are consistently low.
- The gaseous fuels mainly, LPG will see growth in major cities in the interim period as a substitute for gasoline to check the growth of CNG which adversely affect the refining margins. This is a short-term fuel, which will be sold till matching EURO IV graded petrol and diesel is produced and sold. There are environmental issues associated with the use of LPG in India

based on the quality of auto LPG sold in India, which also need to be addressed.

- The growth of LPG will also be aided by the fact that major infrastructure is not necessary for the growth of LPG markets, which is a distinct advantage over CNG.
- The development of CNG markets will be dependent on the infrastructure, both for transmission and distribution of natural gas and CNG respectively in addition to the availability of natural gas.
- The automobile and oil industry should pursue vigorously with the government the issue of credits for achieving lower emission norms and for introduction of technologies using renewable fuels etc as is practised in some developed countries.

Introduction

The quest for better environment and energy efficiencies has been a driving force for the scientific community to thrive for new generation automotive technologies. There have been considerable improvements in the conventional automotive traction technologies and the internal combustion engine the dominant prime mover for the transport for about a century, has reached a tremendous level of sophistication in the process. Traction technologies have also been adapted to accommodate post combustion emission control devices that reduce total emissions at the local level. In addition to this several clean fuels(unleaded gasoline, LSD, LPG and CNG) and renewable fuels(ethanol, bio-diesel) have also been introduced that further aid in reducing the emission levels. The usage, advantages and concerns pertaining to these new generation automotive fuels have been discussed in detail in chapter 4.

Whilst considerable development has occurred in the areas related to the combustion based automotive traction technologies including fuel quality improvement, recent years have seen an increased effort to develop alternatives. The demand for a zero or near zero local emission traction technologies have led to emergence of alternate power pack based traction technologies. The alternate power pack based traction technologies that have received the attention of transport planners, vehicle manufacturers and research community in the recent and past are mainly classified as;

- Electric Vehicles
- Hybrid Electric Vehicle
- Fuel Cell Vehicles

In all of the above mentioned vehicles electricity alone, or in combination with an internal combustion engine is used as a source of energy for providing traction to the vehicle. The source of electricity in an electric vehicle is an on-board storage battery, in a hybrid electric vehicle the source is again a battery but in combination with generator coupled internal combustion engine and finally in a fuel cell vehicle, it is the fuel cell which acts a source of electricity generation. The details of these alternate traction technologies and their validity in the current scenario has been discussed in this chapter.

Electric vehicles

An electric vehicle is a motor vehicle, such as an automobile, truck, or bus, that uses a rechargeable battery for fuel, replacing gasoline, diesel or other types of combustible fuels. An electric vehicle or an EV (as it is popularly known) utilizes an electric motor or, in some applications, more than one motor to propel the vehicle. Electric vehicles are similar in many aspects to vehicles powered with internal combustion engines.

The energy stored in the Electric Vehicle's rechargeable battery supplies power to the motor controller. The motor controller is a device, which controls the amount of power supplied to the electric drive motor(s) based on the position of the accelerator pedal. The electrical power supplied to the electric drive motor(s) is used to generate an electromotive force, which turns the shaft of the electric motor(s). This shaft is coupled to the wheels of the vehicle and causes movement either forward or reverse, depending on the direction the shaft is turning.

Refueling an electric vehicle consists of plugging in the vehicle's charge plug into an outlet that is specifically designed for charging an electric vehicle. Recharging time varies, depending on the battery type, capacity and the voltage/current output of the charger. Most EV's can be recharged in about 6 hours.

Batteries for electric vehicles

To provide for affordable road electric vehicles with acceptable performance in mixed traffic, the motive power batteries must have certain essential features. The key requirements of a battery system of an electric vehicle is its specific energy, specific power, life cycle and cost.

Storage batteries for electric vehicles

The function of these batteries is to store a fixed amount of chemical energy and be capable of recharge when the electrochemically active material in them have been exhausted. The critical factor in usage of EVs is the driving range of the vehicle. Although the vast majority of journeys in private automobiles, covers less than 30 miles, the driver is secure in the knowledge that, whenever he chooses, he can cover 250 miles, refill the fuel tank and drive a further 250 miles. The electrical vehicle traction batteries therefore have to be selected, keeping in considerations, certain comfort levels of the vehicle driver. Several storage batteries have been proposed for electric vehicles and the brief description is presented in the following section.

Critical features of the batteries to be used for automotive applications

- High energy per unit mass/ volume – for long driving range
- High peak power – for good acceleration and hill climbing
- High energy efficiency – for economic use of input electricity
- Low self discharge – to minimize energy loss on standing
- Fast recharge – for rapid refueling
- Long service life – for low depreciation cost
- Low cost – to gain customer acceptance
- Zero or low maintenance – for little routine attention
- Independent of ambient conditions – to withstand both extremes and variation in temperature
- Robust design and operation – to sustain abuses, both electrical and mechanical
- Environmentally benign – use of non toxic materials
- Proven safety – to ensure safety while usage under both normal driving and crash conditions.

The lead acid batteries

The majority of EVs on the streets at present employ lead-acid batteries and these are characterized by a high level of specific power which invests the vehicles with acceleration capabilities at least as good as those of the internal combustion engine equivalent. Specific energy of lead acid batteries are about 30 Wh/ kg and 40 Wh/ kg for sealed type and vented type lead acid batteries respectively. Electric automobiles using lead acid batteries are likely to be limited to a range-per-charge of around 160 km. Other battery chemistries are likely to be developed at present in pursuit of high specific energy and these may increase range-per-charge to 240 km or, ultimately, to 320 km. Cycle life is in the range of about 500–700 cycles in most of the cases.

There are three types of lead acid batteries in common use:

- Batteries with excess of flooded electrolyte
- Low maintenance batteries with a large excess of electrolyte
- Batteries with immobilised electrolyte and with a pressure sensitive valve usually referred to as valve-regulated lead acid (VRLA) or sealed lead-acid (SLA) batteries.

The conventional flooded type lead acid battery requires checking of specific gravity of electrolyte, periodic addition of water to maintain electrolyte above the plates and need to recharge soon after the battery discharge to prevent hard sulfation that causes loss of capacity. The emission of acid fumes causes

corrosion of the metallic parts in the vicinity of the battery. The seepage of acid on the top cover leads to leakage current resulting in increased self-discharge and ground shunt hazards.

Towards the end of the twentieth century the lead-acid battery underwent a significant functional revision. For most of its long history the battery had operated with its plate immersed in a mobile electrolyte and provision has been made for oxygen and hydrogen produced during overcharge to be released freely into the atmosphere. The dissipated gases represented a loss of water from the electrolyte and therefore had to be replaced in regular maintenance operation.

The modern valve-regulated lead acid (VRLA) battery operates on an 'internal gas cycle' in which oxygen evolved during the latter stages of charge, and during overcharge of the positive electrode transfers through a gas space to the negative electrode to a less negative value and thus reduces hydrogen evaluation to a very much lower level. A pressure relief valve is provided to ensure that even the small amounts of hydrogen produced do not generate high pressure.

The changes made to the construction of the batteries in the move to the valve regulated design have resulted in resolution of several critical issues and thus the VRLA is a battery that requires no maintenance, presents no threat of acid spill and can be deployed with minimal foot print.

In order for the VRLA batteries to be successful in electric vehicles, the principal requirements are for the reliability and life. The main thrust of the research are to understand and overcome the failures mechanisms so that battery presents a viable cost of ownership option. The current level of R&D on the development of lead acid batteries is being carried forward through the Advanced Lead Acid Battery Consortium. The Table 5.1 compares the current status of lead acid batteries.

The key issues which in past have made the lead acid batteries fail are short life, high maintenance, and inadequate energy density. Additional issues such as safety, environmental impact and material recyclability are becoming more critical than in the past.

Table 5.1 Key parameters for Lead - Acid Batteries for Electric Vehicles

	Purchase Costs (\$/kWh)	Specific power (W/kg)	Specific energy / range (Wh/kg /Miles)	Recharge time	Cycle life	Cost of ownership (\$/ mile)
ALABC Targets	150	150	50	50%-5 min	500 cycles	0.07
			100	80%-15 min		
				100%-4 hrs		
1992	200	150	25	100%-8 hrs	75 cycles	1.09
			50			
1995	150	150	35	50%-5 min	500 cycles	0.10
			75	80%-15 min		
				100%-4 hrs		
1998	100	150	48	50%-5 min	800 cycles	0.04
			100	80%-10 min		
				100%-30 min		
Assumptions						
\$ 0.10 /kWh for electricity, 16 kWh battery in vehicle, 80% efficiency, 80% depth of discharge						

Source Moseley, 2001

Nickel metal hydride batteries

Today's lead acid batteries must be recharged after travelling short distances, limiting the driving range of EV's. Under a co-operative agreement with the US Department of Energy, the United States Advanced Battery Consortium (USABC) has developed nickel metal hydride (NiMH) battery technology that expands the driving range of the EVs. NiMH batteries capable of meeting the power requirements for EV propulsion have been demonstrated in more than 1000 vehicles in California. Bench tests and recent technology improvements in charging efficiency and cycle life at elevated temperature indicate that NiMH batteries have realistic potential to last the life of an EV, or at least ten years and 10,000 vehicle miles. Several battery companies now have limited production capabilities for NiMH EV batteries, and plant commitments in 2000 could result in establishment of manufacturing capacities sufficient to produce battery quantities required under the current ZEV regulation for 2003. Current NiMH batteries have specific energies of 65-70 Wh/ kg, comparable to the technologies of several years ago, and major increases are unlikely. If NiMH battery weight is limited to an acceptable fraction of EV total weight, the range

of a typical family EV in real world driving is limited to approximately 70 to 100 miles on a single charge.

Despite extensive cost reduction efforts of the leading NiMH EV battery developers, NiMH battery cost remains the largest obstacle to EV commercialisation in the near term. Battery manufacturers and some carmakers projected future NiMH EV battery costs for increasing levels of production. From these projections, battery module specific costs of at least \$350/kWh, \$300/kWh and \$225–250/kWh can be estimated for production volumes of about 10k, 20k and 100,000 battery packs per year, respectively. To the module costs, at least \$1,200 per battery pack (perhaps half of that amount in true mass production) has to be added for the other major components of a complete EV battery, including the required electrical and thermal management systems. On that basis, and consistent with the Panel's estimates, NiMH batteries for the EV types now deployed in California EV would cost EV manufacturers between \$9,500 and \$13,000 in the approximate quantities (10k–20k packs per year) required to implement the year 2003 ZEV regulation, and approximately \$7,000 to \$9,000 at the 100,000 packs per year level. These projections exceed the automobile manufacturers' cost goals by about \$7,000 to \$9,000 in the nearer term and by approximately \$5,000 at automotive mass production levels (Andermann, Kalhammer and MacArthur, 2000).

Nickel cadmium batteries

At present, Nickel cadmium batteries (NiCd) batteries represent the best balance between specific energy, specific power, cycle life and reliability. The NiCd battery has a positive plate of nickel oxy-hydroxide (NiOOH), a negative plate of Cadmium and an aqueous solution of KOH for the electrolyte. The battery can endure a lot of abuse both physically and electrically. Also the alkaline electrolyte does not enter into the discharge reaction as the acid does in the lead-acid battery and hence does not get depleted as the battery discharges.

Due to their high cranking power, lower weight and corrosion free atmosphere, nickel cadmium batteries have found ample applications in defense and space. Nickel cadmium batteries are produced mainly in either sintered plate or pocket plate configuration. Recently, fiber nickel cadmium batteries which employ fibres of foam nickel have been developed and commercialized. Nickel cadmium batteries are generally designed to be positive limited and, akin to lead acid batteries, can be sealed.

Nickel cadmium batteries, however, suffer from the memory effect, which burdens the user with having to at least occasionally follow a time consuming

recharging regime in order to maintain the rated capacity. The effect appears to be due to the growth of abnormally large crystals on cadmium electrode. These crystals reduce the surface area of the cadmium electrode, thereby increasing the battery's effective internal resistance. Besides, nickel cadmium batteries store only slightly more energy per unit weight than lead-acid units, have a fairly high-rate of self-discharge at high temperatures. Worst of all, cadmium is an awful poison that can contaminate environment (Andermann, Kalhammer and MacArthur, 2000).

Lithium ion batteries

The reliability of the Li Ion EV batteries in the ALTRA EV has been excellent up to now, but the battery durability test data obtained in all major lithium ion EV battery development programs indicate that battery operating life is typically only 2–3 years at present. Current Li Ion EV battery technology also does not pass some of the tests used to gauge battery safety under simulated abuse conditions. Resolution of these issues, the production of pilot batteries and their in-vehicle evaluation, and fleet testing of prototype Li Ion batteries meeting all critical requirements for EV application are likely to require at least three to four years. Another two years will be required to establish a production plant, verify the product, and scale up to commercial production. Based on cost estimates provided by developers and the Panel's own estimates, these batteries will cost substantially more than NiMH batteries at a production volume of around 10,000 packs per year. Even in much larger production volumes, Li Ion EV batteries will cost less than NiMH only if substantially less expensive materials become available, and after manufacturing technology combining high levels of automation, precision and speed is developed.

Lithium metal polymer EV batteries are being developed in two programs aimed at technologies that would cost \$200/kWh or less in volume production. However, these technologies have not yet reached key technical targets including cycle life and are in the pre-prototype cell stage of development. It is unlikely that the steps required to achieve commercial availability of Li Polymer batteries meeting the performance and life requirements as well as the cost goals for EV propulsion can be completed in less than 7 to 8 years (Andermann, Kalhammer and MacArthur, 2000).

Lithium polymer batteries

Another candidate appears to be lithium-polymer batteries. Polymer based system offers compactness, ruggedness, leak-proof and flexible geometry, and

high energy density. However, the difficulty being faced is the scaling up the miniature lithium battery technology to sizes and configuration required for electric vehicles.

Table 5.2 Performance comparison between different batteries

Type	Nominal voltage (V)	Specific energy (Wh/ kg)	Energy density (Wh/ l)	Specific Power (W/ kg)	Power density (W/l)	Self discharge (% month)	Cycle
Lead - acid	2.0	35	70	~200	~400	4-8	250-500
Lithium - ion	3.6	115	260	20-250	400-500	5-10	500-1000
Lithium - polymer	3.0	100-200	150-350	>200	>350	~ 1	200-1000
Nickel - cadmium	1.2	40-60	60-100	140-220	220-350	10-20	300-700
Nickel-metal Hydride	1.2	60	220	130	475	30	300-500

Source : <http://www.solardome.com/solardome51.html>, as on August 12, 2002

Advantages and Disadvantages of Electric vehicles

Advantages

- The primary focus of EV's is to reduce the amount of noxious gases that are released into the air due to the combustion process of an internal combustion engine. **An electric vehicle produces zero emissions at the site where it is used.** Though it is true that energy to charge the EV is made at power stations that produces pollutants. But there are strict norms for controlling pollution at the power plant side. Also, it is much easier to control pollution at a single power plant site than at millions of vehicles running on the road. And since power plants produce an excess of power at night, when the demand is low, EV owners can use the excess power by recharging at night. This makes the power plants more efficient. In addition to this EVs could also use renewable energy based electricity for recharging the vehicle batteries.

- **Electric vehicles are much more energy efficient than ICE vehicles.** Considering only the vehicle itself, EVs are more efficient than ICEVs. A battery-operated EV operates at 46% efficiency, whereas an ICEV operates at 18% efficiency. This implies that 46% of the electrical energy taken from the wallplug to charge the electric propulsion batteries is delivered to the drive wheels as useful work compared to only about 18% of the energy dispensed into the fuel tank as liquid motor fuel in an ICEV. The EVs can also recover the kinetic energy of the vehicle via regenerative braking.
- The propulsion system in EVs is much more efficient, therefore **energy losses through the transmission and idling simply do not exist.** Because there is no transmission, acceleration is "seamless"; therefore no jerking or noise, the ride is just nice and smooth.
- The other advantages include increased reliability, better operating performance, cleanliness and absence of fire hazard.

Disadvantages

- **High capital vehicle cost (eg. due to high cost of batteries)** EVs currently cost approximately **50–100% more** than their conventional counterparts. The capital costs of battery electric buses are substantially higher than those of similarly sized diesel transit buses. A 25 foot battery electric shuttle bus is slightly more than **twice as expensive** as a comparable diesel model when the battery electric bus is equipped with a lead acid battery pack. With the larger 33 foot buses, the cost premium for battery electric buses falls to approximately **33 percent**.
- Limited vehicle range due to the amount of energy which can be stored in batteries
- Typical battery recharge time of 6–8 hours (slow charge)
- Increased vehicle mass from the battery pack which increases vehicle mass by 300–900 kg and therefore energy consumption
- Potential problems with emissions from electricity production especially in old power plants fuelled with coal.

Manufacturers of electric vehicles

The air quality restriction imposed by US Government, in particular of the California State has, initiated a revolution amongst the automotive manufacturers that is focused towards producing zero emission vehicles. This has also triggered a race amongst the vehicle manufacturers to come up with

battery operated vehicles that have comparative performance with convention internal combustion engine based vehicle but however, zero exhaust emission at local level. The giants of the automobile industry as well as other new players have come up with variety of versions of electric vehicles which are listed in this section.

General Motors EV1

EV1 is a purpose built electric vehicle with two battery technologies: An advanced, high capacity lead acid, and an optional Nickel Metal Hydride. The Gen II EV1 is powered by a 137 horsepower, 3 phase AC induction motor and uses a single speed dual reduction gear set with a ratio of 10.946:1. The propulsion system has an improved drive unit, battery pack, power electronics, 6.6 kW charger, and heating and thermal control module. A set of 26 valve regulated high capacity lead acid (PbA) batteries are the new standard for the EV1 battery pack. The EV1 with the high capacity lead acid pack has an estimated real world driving range of 55 to 95 miles, depending on terrain, driving habits and temperature. The range with the NiMH pack is even greater. Again, depending on terrain, driving habits, temperature and humidity, estimated real world driving range will vary from 75 to 130 miles. The EV1 can be charged safely in all weather conditions with inductive charging. Using a 220 volt charger, the second generation GM charging from 0 to 100% for the new lead acid pack takes up to 5.5 to 6 hours. Charging for the nickel metal hydride pack, which stores more energy, is 6 to 8 hours. During braking, the electric motor generates electricity (re-generative) which is then used to partially recharge the battery pack. The structure weighs 290 pounds and is less than 10% of the total vehicle weight. The EV1 has an electronically regulated top speed of 80 miles per hour.

Toyota RAV4

Toyota has begun selling its zero emission RAV4-EV (electric vehicle) to retail customers in California. The Toyota RAV4-EV is a zero emission, state-of-the-art electric version of Toyota's popular RAV4 sport utility vehicle (SUV). In 1997, Toyota began making the RAV4-EV available nationally through a special fleet lease program to major corporations, government agencies and utilities. Today, RAV4-EV is one of the best selling electric vehicles in the country with more than 900 in service nationwide, including 700 on the road in California.

The RAV4–EV is powered by a maintenance–free, permanent magnet motor, producing 50kW of power (equivalent to a 67 horsepower gasoline engine). It's a real vehicle with a top speed of 78 mph, and provides style, room, practicality and utility. With a range between 80 and 100 miles per charge, RAV4–EV can be used to meet most daily driving needs.

The RAV4–EV has a manufacturers suggested retail price (MSRP) of \$42,000, but a \$9,000 incentive from CARB and a \$3,000 IRS credit brings the price down to \$30,000, which includes an in–home charging device. There are also three special introductory lease options, which also include the use of the charger.

Table 5.3 Manufacturers of electric vehicle

THINK Mobility, LLC - <http://www.thinkmobility.com/>

Electric cars, bikes, low speed vehicles (LSVs); division of Ford Motor Co.

AeroVironment Inc. - <http://www.aerovironment.com/>

Supply products and technology for clean energy and efficient vehicles. Products include unmanned aerial vehicles, electric and hybrid vehicle systems, distributed energy and atmospheric systems.

CorbinMotors.Com - <http://www.corbinmotors.com/>

Building environmentally friendly vehicles for the next century: electric and hybrid motors, and three wheel, one seat commuter vehicles.

Solectria Corp. - <http://www.solectria.com/>

Designs and manufactures electric, hybrid electric, and fuel cell technology products.

SwissLEM AG - <http://www.swisslem.com/>

TWIKE electric bicycles and three wheel cars.

AC Propulsion, Inc. - <http://www.acpropulsion.com/>

Developer, licensor, manufacturer of system and component technology for electric vehicle drive systems. Home of zero high acceleration, 200 h.p., 2-seat roadster sports car.

Reva Electric Car Co. - <http://www.revaindia.com/>

Makes Reva two door hatchback; 2 adults, 2 children; top speed: 65 kmph, range: 80 km. India's first electric car (EV), to be produced by the Mahindra Group.

ISE Research-ThunderVolt - <http://www.isecorp.com/>

Low-emission electric and hybrid-electric vehicles (buses, trucks, tow tractors, trams) and components.

Planet Electric, Inc. - <http://planetelectric.com/>

Scooters and off-road vehicles: utility, service, neighborhood, personal carriers, ATV's, golf cars, racing karts.

Gorilla Vehicles - <http://www.gorillavehicles.com>

The Gorilla Electric All Terrain Vehicle (ATV), used as a neighborhood electric vehicle, golf cart, utility vehicle, and for recreation.

Electric Vehicles (Thailand) Co., Ltd. - <http://www.evthai.com/>

Electric scooters, bicycles, golf and utility cars, three-wheelers and shuttles.

Electric Vehicle Corp. - <http://www.shout.net/~mmd/burro/>

Makes BURRO personal vehicle for off road sidewalk use by one person in seasonal weather, up to 250 pound payload area.

ULB Corp. - <http://www.gooler.com/>

Makes golf, neighborhood, and small utility vehicles.

Jincheng group - <http://us.jincheng.com/>

Golden Dolphin, an electric bicycle.

Frazer-Nash Research Ltd. - <http://www.frazer-nash.com/>

Go-karts, utility vehicles, golf buggies, tour trams, city cars and more.

Bend Motors - <http://www.bendmotors.com/>

The Shredder, a three-wheeled single seater.

A-Pro Cycles, Inc. - <http://www.aprobike.com/qtee/>

Minima electric scooter, maximum speed: 20 kmph, maximum range: 28 km.

Global Electric Motorcars - <http://www.gemcarsonline.com/>

Four-wheeled transportation for two or four people, with a maximum speed of about 25 miles per hour.

Spark Electric Transportation - <http://www.ezebike.com/>

EZ-E-Bike electric powered bicycles and scooters.

Edge Tech International, Inc. - <http://www.1999.com/solarscooter/>

Portable three-wheel scooters.

Segway - <http://www.segway.com.edgesuite.net/>

Company developing and manufacturing Dean Kamen's invention, the Segway Human Transporter - an electric scooter use in pedestrian areas, not on the road.

Electric vehicle manufacturers in India

The EVs were introduced in India about a decade back and a number of vehicles are already on the road. Bharat Heavy Electrical Limited has developed and commercialized a 16 seater EV bus. The operational data in the initial stages were extensively used for making improvements in performance of the bus. The change were incorporated in the vehicle control system and design. Currently the vehicle is being deployed all over the country. Battery operated three wheelers are also available from various manufacturers and efforts are on to make these three wheelers commercially viable. The details of EVs operating in India and their manufacturers are listed in the Table 5.4. Apart from these players Bajaj auto and Eicher are also planning to enter three wheeler EV market. Ashok Leyland has developed a hybrid EV bus with the BSIR support. The project is still in the demonstration stage.

Table 5.4 Electric vehicles of India

Manufacturer	Vehicle description	Battery capacity	Pay load	Expected range (km)	Battery make
Eddy Current Control (I) Ltd., Coimbatore	Love Bird Car	36V, 150 Ah	Couple+Child	44	--
Maini Group, Bangalore	REVA Car	48 V, 200 Ah	2 Adults + 2Children	80	Exide 8X3EV200
Mahindra & Mahindra, Mumbai	3 Wheeler Bajaj	72V, 200 Ah	10 seater	90	Exide 12X3EV200
Scooters India Limited, Lucknow	3 Wheeler	72V, 200 Ah	8 seater	80-100	Exide 12X3EV200

Source : Barjatta, 2001

Table 5.5 Battery Electric Light Duty Passenger Vehicles Sales/ Leasing (1996-2002)

Year/Model	Chrysler EPIC	Ford Ranger EV	Ford Baker/USPS	GM EV1	GM S-10 Electric	Honda EV Plus	Nissan ALTRA	Toyota RAV4-EV	Total
1996	N/A	N/A	N/A	39 (PbA)	N/A	N/A	N/A	N/A	39
1997	17	27		264 (PbA)	278	105	N/A	69	760
1998	0	310	N/A	258 (PbA/NiMH)	99	133	30	359	1189
1999	129	533	N/A	138 (PbA/NiMH)	123	62	30	255	1270
2000	60	389	N/A	154	0	0	50	106	1017
2001	0	53	500	0	0	0	20	160	733
2002 (1st quarter)	0	0	0	0	0	0	0	218	218
Total	207	1312	500	1110	500	300	130	1167	5226

Source www.evaa.org/evaa/pages/ele_ev_market.htm as viewed on August 1, 2002

Review of policy and regulation to promote electric vehicle - International status

United States

Zero emission vehicles (ZEVs) are a key element of California's plan for reducing air pollution caused by automobiles. ARB is committed to the successful introduction of ZEVs and is taking steps to ensure the market is ready.

The incentives are being provided by the government to promote zero emission vehicles. Because ZEVs are a new technology and are currently produced in very limited quantities, they are more expensive than conventional vehicles. To enhance marketability in the near term while costs are high, it is vital to provide monetary and non-monetary support in the form of incentives. There are a number of federal, state, local and private incentive programs currently available for ZEVs.

Federal Incentives in US

- Tax credit for 10% of the cost of an EV, up to \$4,000 (www.fueleconomy.gov as viewed on August 28, 2002). Up to \$4000 federal tax credit is available for 10% of the purchase price of an EV. Beginning in 2001, the size of the credit is reduced by 25% per year until the credit is fully phased out. To qualify for the credit, the vehicle must be powered primarily by an electric motor drawing current from batteries or other portable sources of an electric current. All dedicated, plug-in only EVs qualify for the tax credit. All series and some parallel Hybrid electric vehicles meet these qualifications. The tax credit for EVs is available for business or personal vehicles.
- Elimination of the luxury tax for alternative fuel vehicles.

Utility incentives in US

- Los Angeles Department of Water and Power provides discounts of \$0.025 per kilowatt hour (kWh) for electricity used to recharge EVs.
- San Diego Gas and Electric offers a discount rate of \$0.036/kWh for electricity used to recharge EVs during off-peak time periods. They have a total of \$50,000 in seed money to help local businesses and governments install charging stations in its service area.
- Sacramento Municipal Utility District (SMUD) offers a discount rate of \$0.04187/kWh for electricity used to recharge EVs during off-peak time periods.

- Pacific Gas and Electric offers a discount rate of between \$0.044/kWh to \$0.051/kWh for electricity used to recharge EVs during off-peak time periods.
- Southern California Edison offers a discount rate of \$0.07825 per kWh for electricity used to recharge EVs during off-peak time periods.

Infrastructure Incentives in US

- The Bay Area Air Quality Management District provides funding assistance to public agencies for EV infrastructure through its "Charge" program.
- The City of Vacaville and the City of Dixon provide incentives for installation of public EV chargers.
- Ventura County provides incentives for installation of public EV chargers.
- LA DWP provides incentives for installation of public EV chargers in the City of Los Angeles.
- The CEC offers electric vehicle infrastructure incentives to fleet operators and consumers through electric vehicle automakers.
- San Diego APCD has incentives for public chargers. Maximum business tax deduction of \$100,000 for electric recharging site.

California state and local incentives

- The state-wide Zero Emission Vehicle Incentive Program (ZIP) provides up to \$3,000 per year for three years towards the purchase or lease of EVs.
- The City of Vacaville and the City of Dixon provides \$5,000 towards the lease of an EV purchased or leased in their area.
- The California Energy Commission (CEC) provides incentives for certain hybrid electric vehicles and alternative fuel vehicles through The Efficient Vehicle Incentive Program.
- The Riverside Public Utility provides rebates of 10% of the vehicle's purchase price up to \$5,000 towards new passenger electric vehicles that the Riverside Public Utility deems eligible.
- The Los Angeles Airport (LAX) offers free parking and charging for EVs in certain identified lots.
- The City of Sacramento Off-Street Parking Department offers free parking to EVs with an EV parking pass in downtown parking lots.
- Electric vehicles with HOV(High Occupancy Vehicles) stickers can park for free at the metered parking spaces in the City of Santa Monica.

- SB 1782 (Thompson) exempts from the vehicle license fee, the incremental cost associated with purchasing or leasing an alternative fuel or electric vehicle that meets ultra-low emission standards.

The EV loan programs in United States of America

To encourage the leasing of EVs by public fleets, the Air Resources Board, the South Coast Air Quality Management District, and the Department of General Services have launched the EV Loan Program. Through this short term loan program, state and local governmental agencies can experience the benefits of an EV.

At no cost to program participants, the EV Loan Program provides:

- An electric vehicle for one month
- Temporary installation of any charging infrastructure that is needed
- A toll-free phone number for the convenience of customers with prospective questions

Vehicle pick-up and training for use is arranged for the customers. After the loan, the driver/ customer will have the opportunity to evaluate the vehicle and describe their experiences. If the customers decides that EVs would make a good addition to their fleet, the board help lease a vehicle and arrange for installation of charging equipment.

Loan Program benefits for public fleets in US

- A no-risk opportunity to experience the many benefits of electric vehicles
- Gain "real-world" experience with electric vehicles
- Develop a good understanding of vehicle range, reliability, and operating costs
- Determine if these vehicles meet the fleet needs
- Make an informed decision on whether to lease an electric vehicle
- Showcase the agency's concern about environmental issues.

Program Eligibility

The loan beneficiary must represent a state or local public agency that is interested in electric vehicles, but is not currently leasing one. The beneficiary(customer) must be willing to pick up and return the vehicle to a State garage or, in outlying areas, another convenient location, and use the vehicle throughout the loan period. The customer has to meet minimum

electrical requirements for the installation of charging equipment, or have access to electric vehicle charging facilities.

Vehicles available for lease

- GM EV1
- Honda EV Plus
- Chevrolet S10 pickup truck
- Ford Ranger pickup truck
- Toyota RAV4

The program is open to public agencies, including the State of California, the University of California, California State University, and political subdivisions of the state, including city and county government, and Community College Districts.

The California Energy Commission also offers electric vehicle infrastructure incentives to fleet operators and consumers through electric vehicle automakers. Under the program, the Energy Commission provides up to \$750 to automakers for each EV they lease or sell through the Energy Commission's program. This incentive must be matched dollar-for-dollar by the automaker and can be used for charging equipment or installation hardware and/or labor.

The promotional effort of EVs in other countries is described below(Sahay & Mondal, 2001):

Italy

Road traffic incentives

- Free access to limited traffic zones (according to local authority discretion)
- economic incentives

Economic incentives

- Exemption for five years on road taxes
- 50% cut in insurance cost
- Subsidy by Lombardy region's Environmental-energy council
- Subsidy by Regione Friuli venezia Giulia

Belgium

Economic incentives (law proposals)

- Exemption from road taxes
- Government subsidy of 150.000FB for each vehicle bought

France

Road traffic incentives

- Road traffic incentives
- Placing of battery charging point in some Parisian parking

Economic incentives

- Government subsidy on buying EV of 5000FF
- EDF subsidy on buying EV of 10000F

Switzerland

Economic incentives for LEV project

- 10% discount by car makers, federal subsidy of 27%, and the cantonal one of 13%. The canton will also drop registration taxes while private business will give discounts for leasing and renting these vehicles.

Road traffic incentives

- Regional and city planners will ease parking and residential rules for owners of electric vehicles. The new rules include exemption from parking fees and possibility to park twice as long as conventional vehicles. There are battery recharge outlets for electric vehicles bought in Mendrisio and in the region. Urban planners through zoning laws are directing the owners and builders of multiple dwelling to set recharge points for renters who own electric vehicle. The number of vehicles in India has increased dramatically, from 4.3 million to over 35 million just in the last fifteen years. The entry of various international vehicle manufacturers in India, ease of financing facilities for vehicle purchases, growing urban population coupled with deteriorating public transport systems are all contributing to an ever increasing vehicle population. Exacerbating the urban pollution problem is the high number of two and three wheelers on roads that are running on what can be safely described as vintage technology. The total number of two and three wheelers is currently more than 25 million. Though air pollution has crossed threshold level in urban centers., there exist a solution to air pollution problems. Long range solutions include displacing diesel and gasoline run vehicles by vehicles which run on alternative fuels.

Indian perspective on EV & its commercialisation

Relevance of the Electric Vehicle Technology to India

The current electric vehicle technology uses lead acid batteries to run an electric motor. Several shortcomings of this technology have been cited, around the

world, as the reason for it being not commercially viable. However, many of these shortcomings are not relevant in the Indian context and therefore make the EV a more viable technology for India than for the developed world (Agarwal, 2001). The arguments in favor of EV, for the Indian market can be summarized as follows.

- Electric vehicles are limited in their range and performance. However, unlike in the developed world, personal transport in India is largely used within a single urban area. Inter-city or long distance travel is more commonly undertaken through public transport rather than by using personal vehicles. In three metropolitan cities of Mumbai, Kolkatta and Delhi, the average daily travel by personal vehicles is about 25–30 kms. The situation in the other cities is not very different. The average speed of the Indian traffic is very low because of the narrow roads and inadequate number of highways. Thus, the average distance over which a personal vehicle is driven per day and the average speed of travel are well within the range of the EV technology available today. Thus there is a good match between what an electric vehicle technology can deliver and the mobility needs of most Indian roads.
- Reliable power supply, at reasonable price, is a must for electric vehicle industry to develop. Although India is very short of electrical power and needs substantial addition to the generating capacity to meet the existing shortfalls, yet load factors of power plants have only been around 60%. The demand of the off-peak power is much lower than the peak demand. This clearly indicates that there is considerable room for developing a system that could use off-peak power, at lower cost, without straining the power system capacity. In fact there is scope for increasing the supply by as much as 30–40% by improving the plant load factor, without adding to the system capacity. By introducing time of the day tariffs, future electric vehicle customers can be effectively encouraged to charge their vehicles during the off-peak hours at a considerable discount in the tariff. Even if the power tariffs are rationalized and the rates go up, lower off-peak tariffs could still make electrical vehicles a cheaper alternative.
- Even if thermal power stations are used to generate additional power for charging electric vehicles, effective emission control systems could be employed and these power stations could be located away from the urban centres. It would be easier to implement emission control systems on a few power plants than on millions of vehicles moving all over the cities.

- The Indian consumer is very cost sensitive and would prefer a lower operating cost electric vehicle to a higher operating cost gasoline vehicle. A major attraction for the customer would be the low potential low operating cost of an electric vehicle, given the price differential between gasoline/ diesel and electricity in India. Though there is considerable variation in the electricity price from state to state and sector to sector, it is rarely more than Rs.3–5 per kWh. As against this, gasoline and diesel prices are around Rs. 30 and Rs. 18 per litre respectively. With this price differential, it would be possible to have a lower life cycle cost/km for an electric vehicle as compared to an internal combustion engine vehicle.

Policy prescriptions for promoting electric vehicles in India

Improving the relative economics of the EVs as compared to the conventional ICEV

An earlier study (Agarwal, 2000) has shown that the life cycle cost of an electric car work out to be about 75% of an equivalent petrol driven car and about 80% of an equivalent diesel driven car. As against the above, a study conducted by TERI had concluded that electric 3-Wheelers can never be commercially viable without fiscal incentives from the government (Dass and Mathur, 1996). While both of these studies have made only approximate calculations of lifecycle costs, they go to show the potential of impacting the life cycle costs through appropriate policy initiatives.

The relative economics of the EV over the ICEV can be improved through the measures that would lead to a more favorable pricing of the inputs for EVs. It is essential that the price of electricity for battery charging is kept as low as possible and its price differential with gasoline/ diesel is kept as high as possible. Pricing electricity for battery charging at domestic rates and not industrial or commercial can do this. A large peak load can be avoided on the system by requiring battery charging stations to install “Time-of-Day” meters and only off-peak power being charged at the domestic rates.

It is also recommended that detailed studies be commissioned to make accurate assessments of the life cycle costs of EVs and ICEVs in selected cities of India. Such studies would provide inputs on the extent of fiscal incentives that are necessary and the specific nature of the incentives. It is expected that with increasing usage, improved infrastructure and continuing research into better batteries, EVs would be able to hold their own against the ICEVs even without the necessary crutches that may be necessary in the initial stages.

Enabling the easier use of EVs

Facilitating the required supporting infrastructure to come up

One of the major constraint with any alternate fuel vehicle is the lack of distribution infrastructure for that fuel, as is evident in the case of compressed natural gas. Fortunately in the case of the EVs the required distribution infrastructure for electricity already exists. Only the charging facilities have to come up.

While those who own garages only need to have a power socket in the garage, those who do not own garages will need to find power sockets close to the parking sites for their cars. In fact those who do not own garage are more likely to be the niche market for EVs, as those who own garages would in all probability constitute a higher income group that may still prefer ICEVs.

It would, therefore be necessary to offer right incentives for private entrepreneurs to set up a network of “power socket banks” at major residential complexes, office complexes, parking lots and other similar locations where users are likely to park their vehicles for a long spells of time. Similarly, petrol pump owners could think of setting up charging and battery exchange facilities where EV owners could exchange their discharged batteries for charge ones, much like an LPG cylinder being exchanged for a filled one (Agarwal, 2001).

All of the above does not require much policy support from the government, except for a supportive pricing policy for EVs. Apart from this, government could set the ball rolling by supportive measure like:

- Offering and initial subsidy on the capital cost of such facilities
- Offering land at reduced rates
- Setting up such facilities in the initial years and then leasing them out to private entrepreneurs for management

Restricting the use of ICEVs in certain parts of a city

This puts physical restraints on the universal usage of an ICEV and would improve the attractiveness of an EV. This could be justified in particularly crowded and environmentally sensitive parts of the city. As an example only EVs have been permitted in the vicinity of the Taj in Agra. Such restrictions on ICEVs can also be imposed in sensitive parts of several other cities. This would very effectively convey government’s serious concern for deteriorating air quality and its recognition of the benefits of the EV technology.

Encouraging the production EVs

Attracting investments into a new product is always difficult, more so when the potential market size is not very clear. Hence the first few manufacturing units face a serious risk and this needs to be mitigated through appropriate policy initiatives. The government could play a supporting role by offering equity participation in joint ventures, with the understanding that its shareholding would be diluted after a certain number of years. By doing this, it would be essentially offering to share the demand risk for EVs and also conveying a signal that it is willing to implement policies that would support EVs.

In addition, tax exemption and other fiscal concessions generally available to new units, both under central and state government policies, should also be available to new manufacturing units.

Mandating a certain proportions of the vehicles sold by a manufacturer to be EVs

The State of California in the US, has enacted legislation to require that by the 1998, at least 2% of the vehicles sold in California by major auto makers must have zero emissions. The percentage is required to rise to 5% in 2001 and 10% in 2003. This enactment by the California Air Resources Board in 1990 has spurred more progress in electric propulsion technology that was accomplished in the previous 20 years by the automobile industry and the US Department of Energy combined. Almost totally because of the mandate, every major auto maker in the US has invested in electric vehicle development.

Cost Economics of EV case study India

Battery storage contributes significantly to the cost of an EV. Currently available batteries have limited energy storage capacities, which limits the driving range of EVs per battery charge. It is necessary to develop and use advanced energy storage batteries and other devices in order to improve the overall performance of the EVs. The use of high energy and power density batteries may reduce weight, size and cost and increase the range (Agarwal, 2001).

Government of India's efforts in R&D, promotion and commercialization of EVs

The Ministry of Non-conventional Sources[#], Government of India is promoting electric vehicles as a means of reducing the consumption of fossil fuels and keeping the ambient air clean and free from pollution caused by diesel and

[#] Source <http://www.mnes.nic.in/frame.htm?publications.htm>, as on August 5, 2002

petrol vehicles. The batteries used in such vehicles can be conveniently charged by renewable energy in eco-friendly manner. The ministry has sponsored projects for the development of EVs and related aspects, including improvement of operational range, performance and durability, besides cost reduction. Research and development projects are currently under implementation for the development of AC vector controlled drive with IGBT inverter and high-energy and power density nickel metal hydride batteries for operating battery powered vehicles. Some nickel metal hydride batteries for electric vehicles and prototypes of battery-powered/ motor assisted cycle rickshaws have been developed.

The Ministry operated a demonstration programme during 1999–2000 by providing subsidy on battery-operated vehicles through the nodal agencies and departments in the state and union territories. The central subsidy was provided for the purchase 20 numbers of 10 seater and bigger passenger vehicles powered by batteries to the extent of 50% of the cost of the vehicle, exclusive of the excise duty, sales tax and other levies. To make these vehicles attractive, it is necessary to improve their technical performance and reduce their overall cost. A proper and effective infrastructure network is also need to support the production and regular operation of BOVs.

One of the major limitations of the EVs, which use conventional lead acid batteries, is the limited driving range of the vehicle per charge of the battery. Therefore, efforts are being made to develop and deploy newer types of rechargeable batteries, which have higher energy and current densities, besides lasting longer (cycle life of about 1000 cycles). Advanced lead acid, nickel metal hydride (NiMH) and lithium batteries are being developed especially for vehicles. A research and development project for the development of nickel metal hydride (NiMH) batteries for operating battery-powered vehicles was implemented jointly by the Central Electrochemical Research Institute (CECRI) unit at Chennai, the Banaras Hindu University (BHU), Varanasi and the Defence Metallurgical Research Laboratory (DMRL), Hyderabad. Prototypes of NiMH batteries have been developed using indigenously available material and tried on an electric bike.

An inter-agency steering committee convened by the Department of Electronics, Government of India has recently begun to take a close look at the use of electric vehicles in India. The committee has suggested setting up a consortium of government and industry that would facilitate the development of technologies needed to make EVs viable, both fiscally and technologically. The

critical technologies in EVs remain batteries and electric drives, while financial issues include tax exemptions and licensing.

There are already provisions in the Motor Vehicles Act that provide flexibility in routes and tariffs for EVs, and some subsidiaries are also in place. One private company recently introduced about 200 EVs in India, while several more plan to tap both the industrial and private markets.

Earlier this year the steering committee organized an Indo-US workshop here that concluded EVs are technological viable but have not yet been made cost-effective. The workshop identified a large market in India for two and three wheeled vehicles but noted that attitudes about costs and the long-term benefits of EVs needed to be addressed.

To promote EV use in India, the workshop suggested supporting the development of high density batteries and electric drives, providing more tax breaks and subsidies, and also mandating EV use in some applications.

Indian Renewable Energy Development Agency(IREDA) has also initiated support program to accelerate the development and rapid commercialization of battery powered electric vehicles. The objective of the IREDA sponsored program is to provide financial and technical assistance to the prospective developments in the EVs related area.

The financial incentives are in terms of subsidy which is fixed at the rate of Rs. 125 per peak watt, subject to a maximum of Rs 1,50,000, to be reimbursed to the manufacturer/ supplier upon satisfactory proof of supply and installation of system. In addition there is 100% depreciation in the first year.

For manufacture of equipment for battery powered vehicles, the financing norms are; upto 70% of the total project cost, at interest rate of 14% per annum, a repayment period of 8 years and maximum moratorium of 2 years.

For equipment financing for battery powered vehicles the norms are; upto 75% of the total project cost, at interest rate of 14% per annum, repayment period of 5 years and maximum moratorium of 1 year^β.

Hybrid Electric Vehicles

Hybrid electric vehicles (HEVs) represent a cross between a conventional automobile and an electric vehicle. They combine an electric drive train, including battery or other energy storage device, with a quickly refuelable power source such as a gasoline or diesel engine, fuel cell, or gas turbine. This refuelable power source, called an onboard power unit or OBPU (also called the hybrid power unit or HPU), generally can recharge the storage device and may

^β Source: http://ireda.nic.in/vsireda/main_new.htm, as on September 24, 2002

drive the wheels either directly (as can the electric motor) through a mechanical drivetrain, or indirectly by providing electric power to the motor.

The combination of conventional and electric propulsion systems offers the possibility of greatly reducing emissions and fuel consumption, while giving consumers both the extended range and convenient refueling they expect from a conventional vehicle. Advanced propulsion technologies are key to the success of HEVs and to the realization of these advantages.

The candidates HPU for use in a commercial HEV propulsion system are:

- Compression-ignition, direct-injection(CIDI)
- Spark-ignition, direct-injection
- Stirling engine
- Gas turbine engine

The idea of a hybrid-electric vehicle naturally evolves from the inherent limitations of the storage battery. As first conceived, a hybrid vehicle would employ an onboard means of generating electricity in order to augment the limited energy available from the battery. The vehicle might then run on battery energy alone when range is within the capability of the battery's energy stores, then use the genset when range requirements exceed the energy stores of the battery. Although simple in concept, the task of achieving significant improvements in energy efficiency depends on the correct integration of subsystems within a sophisticated control strategy that continuously monitors and balances the energy flow onboard the vehicle. When approached as a system, a hybrid power system is no longer a simple battery electric system augmented by a genset. Instead it is an integrated, self-adapting, propulsion system that may ultimately utilize batteries (or supercapacitors) as an energy reservoir for load leveling, rather than in their traditional role of supplying total vehicle motive power.

History

The concept of hybrid vehicle is not new, it was conceived almost a century ago, in 1904, by American engineer H. Piper. For many years, the concept was widely ignored, primarily because of the high development costs and the uncertainty regarding the widespread acceptance of electric automobiles.

A Woods gasoline-electric coupe selling for \$2700 was introduced in 1916. This early hybrid electric vehicle combined a four cylinder gasoline engine with an electric motor and a battery half the size of those used in contemporary

electric cars. It used its electric drive for low speeds and the gasoline engine for higher speeds and to recharge the batteries. Sixty years later, the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976 authorized the U.S. Department of Energy (DOE) to encourage and support research and development of hybrid vehicles. DOE subsequently sponsored major studies beginning in the late 1970s with teams led by the Jet Propulsion Laboratory (JPL) and the Aerospace Corporation.

These studies included both in-depth computer simulations of hypothetical vehicles and the design, construction, and testing of prototype vehicles. The JPL/GE Near-Term Hybrid Vehicle program, which ran from 1978–82, developed a working vehicle, called the HTV–1, with a parallel hybrid drive train .

The real surge in development occurred in 1993, when the Clinton administration announced the formation of the Partnership for a New Generation of Vehicles (PNGV) consortium, consisting of the "Big Three" automobile manufacturers (General Motors, Ford, and Chrysler) and about 350 smaller technical firms. The R&D funds to the tune of about \$500 million a year (about half from federal funds) were allocated to develop a car that can travel eighty miles on a gallon of gasoline. Such a vehicle would be about three times as fuel efficient as a current, comparable, gas fueled automobile. Furthermore, the increase in efficiency is to be achieved without reduction in performance, safety, or comfort in a vehicle that does not cost more and emits one-eighth of the pollutants.

The hybrid vehicle technology

There are three basic HEV configurations;

Series Hybrid Configuration

In this type of configuration, a small fuel-burning engine directly drives an alternator to generate electricity. The electricity is then stored in the batteries or sent to the electric motor, which powers the wheels. The vehicle can operate in the zero emission mode, and when the batteries are drained to a certain level, the engine turns on and begins to recharge them. Since it is less dependent on the vehicle's changing power demands, the engine can operate within a narrower and more efficient range of speeds.

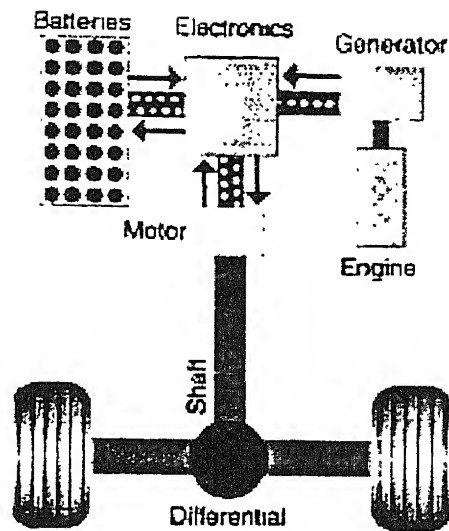


Figure 5.1 Series Hybrid Electric Configuration

The 22 feet HEV bus owned and operated by Chattanooga Regional Area Transportation Authority in United States is a series hybrid. This vehicle manufactured by Advanced Vehicle Systems has a Capstone Turbine that rotates at 96,000 rpm and runs on compressed natural gas.

Parallel Hybrid Configuration

A parallel HEV is configured with two power paths, so that either the HPU engine or the electric propulsion system or both can be used to produce the motive power to turn the wheels. In one approach, the electric only mode can be used for short trips. For longer trips, the engine would provide primary power to the vehicle, with the electric motor assisting during hill climbs, fast acceleration, and other periods of high power demand. In such a vehicle, the engine can be downsized in relation to a similar sized conventional vehicle, reducing weight and providing greater relative fuel economy.

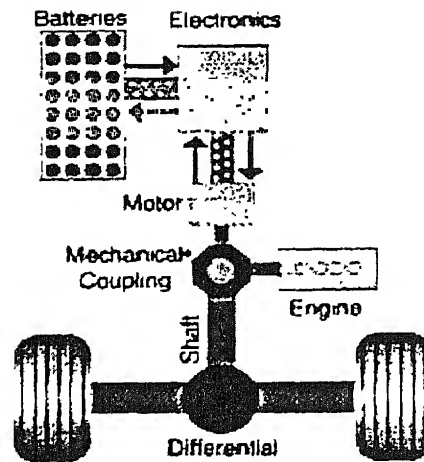


Figure 5.2 Parallel Hybrid Configuration

Dual mode hybrid configuration

Dual mode hybrids are basically parallel hybrids with a separate generator that allows recharging of the batteries. In normal driving conditions, the engine moves both the wheels and the generator, which in turn supplies power to the electric motor and the batteries. During the full throttle acceleration or under heavy load, the motor gets a power boost from the battery. The most successful dual mode hybrid is the Toyota Prius. In the Prius, when the vehicle starts moving, the engine shuts down and only the electric motor drives the wheels, driving the power from its batteries.

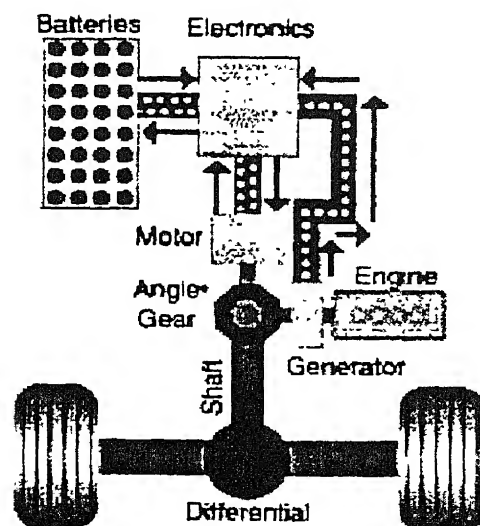


Figure 5.3 Dual mode hybrid configuration

Charge sustaining and charge non-sustaining hybrids

The other classification of hybrids is defined as “charge sustaining” or “charge non-sustaining”. In a “charge sustaining” HEV system, the hybrid power unit is capable of providing sufficient energy, independent of the storage device (usually a battery), to drive the vehicle just like it was a conventional vehicle. As long as the hybrid has fuel for the engine, the vehicle will operate.

The hybrid power unit in a “Charge non-sustaining” HEV is only able to provide recharging energy and cannot supply the necessary energy to drive the vehicle by itself. If an HEV requires an instantaneous 120 kW to accelerate, and the hybrid power unit is only capable of supplying 60 kW, the HEV is considered a “Charge non-sustaining system” because the engine/ generator cannot produce the required energy necessary to accelerate the vehicle. This system must have additional energy from the storage device to meet the energy needs of the vehicle. A “Charge non-sustaining” system is often referred to as a “range extender” because its intended to extend the range of the vehicle.

Advantages & Disadvantages

In terms of overall energy efficiency, the conceptual advantages of a hybrid over a conventional vehicle are:

- Regenerative braking. A hybrid can capture some of the energy normally lost as heat to the mechanical brakes by using its electric drive motor(s) in generator mode to brake the vehicle.
- More efficient operation of the onboard Hybrid Power Unit (HPU), including elimination (or sharp reduction) of idle. A hybrid can avoid some of the energy losses associated with engine operation at speed and load combinations where the engine is inefficient by using the energy storage device to either absorb part of the HPU's output or augment it (or even substitute for it), allowing it to operate only at speeds and loads where it is most efficient. When an HEV is stopped, rather than running the engine at idle, where it is extremely inefficient, the control system may either shut off the engine, with the storage device providing auxiliary power (for heating or cooling the vehicle interior, powering headlights, etc.), or run the engine at a higher-than-idle (more efficient) power setting and use the excess power (over auxiliary loads) to recharge the storage device. When the vehicle control system can shut the engine off at idle, the drivetrain can be designed so that the drive motor also serves as the starter motor, allowing extremely rapid restart due to the motor's high starting torque.

- Smaller, lighter HPU. Because the storage device can take up part of the load, a hybrid's HPU can be downsized. In some cases, the HPU can be sized for the highest sustained loads, not for (higher) short-term acceleration loads. Consequently, the HPU can have a significantly lower power rating than the engine in a conventional vehicle. This allows the engine to be run at a higher fraction of its rated power, generally at higher efficiency, during most driving. Also, the reduced engine weight is mildly beneficial to fuel economy.
- Potential for alternative HPU technologies. Conventional drivetrains use piston engines because such engines do a fair job, when coupled with multispeed transmissions, of efficiently matching vehicle load requirements (static matching), and an excellent job of rapidly boosting or reducing power to match the vehicle's changing loads (dynamic matching). Most alternative power sources do not share these matching characteristics. For example, turbine engines are extremely inefficient at the low loads typical of normal driving, and are slow to respond to changing load, but they can burn a wide variety of fuels and are small and lightweight in relationship to their power output. In a hybrid drivetrain, the storage device could assume the load following role, compensating for the turbine's slow response, and allow the turbine to operate in a high output, efficient mode by absorbing its excess energy output. Remaining roadblocks for turbines include high NOX emissions at high loads and the need for further development of the ceramic materials used to increase their efficiency.

Table 5.6 Energy loss comparison between HEV and ICEV

Energy Source/ Sink	Hybrid Electric Vehicle	Internal Combustion Engine Vehicle
Fuel	100	100
Transmission Losses	- 6	- 6
Idling Losses	0	- 11
Accessory Loads	- 2	- 2
Engine Losses	- 30	- 65
Regenerative Braking	+ 4	0
Total Energy Remaining	66	16

There are counterbalancing factors reducing hybrids' energy advantage, including:

- Potential for higher weight. Although the fuel-driven energy source on a hybrid generally will be of lower power and weight than the engine in a conventional vehicle of similar performance, total hybrid weight is likely to be higher than the conventional vehicle it replaces because of the added weight of the storage device, electric motor(s), and other components. This depends, of course, on the storage mechanism chosen, the vehicle performance requirements, and so forth. The hybrid configurations examined in this report [conventional internal combustion engines (ICEs) and nickel metal hydride batteries] were consistently heavier than their conventional vehicle (CV) counterparts.
- Electrical losses. Although individual electric drive train components tend to be quite efficient for one way energy flows, in many hybrid configurations, electricity flows back and forth through components in a way that leads to cascading losses. Further, some of the components may be forced to operate under conditions where they have reduced efficiency. For example, like ICEs, most electric motors have lower efficiency at the low speed, low load conditions often encountered in city driving. Without careful component selection and a control strategy that minimizes electric losses, much of the theoretical efficiency advantage often associated with an electric drive train can be lost.

Batteries for hybrid electric vehicles

Batteries are an essential component of the HEVs currently under development. Although a few production HEVs with advanced batteries have been introduced in the market, no current battery technology has demonstrated an economical, acceptable combination of power, energy efficiency, and life cycle for high volume production vehicles.

Desirable attributes of batteries for HEV applications

- High peak and pulse specific power
- High energy at pulse power
- High charge acceptance to maximize regenerative braking utilisation
- Long calendar and cycle life.

Technical challenges for HEV batteries

- Developing methods/ designs to balance the packs electrically and thermally
- Developing accurate techniques to determine the battery's state of charge
- Developing abuse tolerant batteries
- Recyclability

The feature comparison of different type of batteries used for HEV applications has been carried out in the following section.

- Lead – acid batteries, used currently in many electric vehicles are used potentially usable in hybrid applications. Lead acid batteries can be designed to be high power and are inexpensive, safe and reliable. A recycling infrastructure is in place for them. But low specific energy, poor cold temperature performance, and short calendar and cycle life, are still impediments to their use. Advanced high power lead acid batteries are being developed for HEV applications.
- Nickel – metal hydride batteries offer reasonable specific energy and specific power capabilities. Their components are recyclable, but recycling infrastructure is not yet in place. NiMH batteries have a much longer life cycle than lead–acid batteries and are safe and abuse tolerant. These batteries have been used in production EVs and recently in low volume production HEVs. The main challenges with NiMH batteries are their high cost, high self discharge and heat generation at high temperatures, the need to control the losses of hydrogen, and their low cell efficiency.
- Lithium – ions batteries are also being tried for HEVs. Li ion batteries have also offer high specific power, high energy efficiency, good high temperature performance, and low self-discharge. Components of Li ion batteries could also be recycled. Though these batteries are suitable for HEVs, but to make them commercially viable for HEVs, further development is needed including improvement in calendar and cycle life, higher degree of cell and battery safety, abuse tolerance and acceptable cost.

Manufacturers of Hybrid Electric Vehicles

Hybrid Electric Cars

The Toyota Prius and the Honda Insight represent the beginning stages of this

"birth" of a new breed of vehicle. In the next few years, several auto makers will introduce hybrid electric vehicles, including the popular Honda Civic and the Toyota Estima, Ford Escape HEV in 2003, and the Dodge Durango and the Chevrolet Silverado/GMC Sierra hybrid pickups in 2004. Volvo's truck division even has plans for a super powerful hybrid semi-truck in the next seven to ten years.

Toyota Prius

The Toyota Prius, meaning "to go before" in Latin, is a parallel type of hybrid that has a 1120 km driving range. Its 58 horsepower, four cylinder engine provides the power to recharge the battery pack as well as to improve performance when driving. This system, called Toyota Hybrid System or THS, automatically switches between gasoline and electricity depending on the driving needs. The electric motor uses 38 individual battery modules, which weigh about 110 pounds total. Sold in Japan for the last several years, the Prius was introduced to the U.S. market in July 2000 and is offered at a retail price of \$19,995. The Prius sedan comes with air conditioning, dual front airbags, daytime running lights, AM/FM stereo cassette, keyless remote, anti-lock brakes, power mirrors and windows.

Honda Insight

The two door, two passenger Honda Insight was introduced in December 1999. Also a parallel hybrid, the Insight uses a 67 horsepower, three-cylinder engine in combination with an electric motor during acceleration. This feature, what Honda calls Integrated Motor Assist, or IMA, improves the Insight's performance. Priced at \$18,080, the Honda Insight comes with a five speed standard transmission, power windows and door locks, AM/FM stereo cassette, anti lock brakes, keyless remote entry and aluminium wheels. Air conditioning is a \$2,000 option. The Honda Insight boasts 98 kms per gallon in the city and 112 km miles per gallon on the highway.

Hybrid Electric Bus

Various types of hybrid electric technologies have also been used for transit buses. The diesel engine is likely to remain the standard power unit for the majority of buses in the world for many years to come.

The concept of the hybrid bus is not new. In fact, there were petrol-electric buses in the 1920's! More recently several manufacturers have built prototypes

and some have now reached volume production. During that time, there have been considerable developments (Urban Transport International, 2000).

Volvo Cumulo

Over fifteen years ago, Volvo Bus Corporation built single—and double—deck prototypes which had a 9.6 litre engine mounted horizontally under the floor in mid-wheelbase, driving through a hydraulic accumulator, to the rear axle, known as Cumulo, the system was developed by an associate company, Volvo Flygmotor.

When the bus slowed down, the braking energy, which would normally be lost in friction, was stored in the accumulator. When the bus moved away from a stop, this power was used to accelerate up to around 30 km/h. At that speed the diesel engine, which was only idling, cut in and powered the bus conventionally.

The theory behind the Cumulo project was that the hybrid arrangement would save fuel, mechanical wear and tear, and also result in lower exhaust emissions. There were also hope the noise levels inside and outside the bus would be lower. In practice, the buses needed near ideal operating conditions, stopping and re-starting two to three times per kilometre. When the buses were caught up in traffic congestion between stops, the diesel engine had to be used more frequently, so the benefits of the system were lost.

Iveco

Other early work was done by Iveco, with Ansaldo and the University of Genoa. They originally experimented with an old city bus, which was converted with a alternator and a large bank of batteries. They occupied much of the floor of the bus, but the performance was rapid and almost silent. At 40 km/h, the loudest noise came from the tyres. The regenerative braking system controlled all deceleration, so that foundation brakes were only required for the last few metres, bringing the bus to a halt, or in an emergency.

This vehicle suffered from two problems which were also apparent on most other early hybrid buses. Firstly, the weight of the batteries was considerable, therefore fewer passengers could be carried if the vehicle was to remain within maximum permitted axle weight limits. Secondly, the batteries were mounted below the floor, at a time when there was growing demand for buses with a large part of the floor only one step above the ground.

Iveco and its partners went on to develop vehicles which had fewer, but more powerful, batteries and therefore less restriction on the number of passengers

carried. Both minibuses and full-size single deckers entered service, principally in Genoa. The small 2.8 litre diesel engine, normally used in the Daily light truck and minibus range, was sufficient to power the alternator in the 12.0 m city bus.

DAB

DAB, which is now Scania's bus factory in Denmark, was also among the early pioneers on hybrid development. Their engineers opted to put the rear axle at the extreme rear and to house all the components of the hybrid drive in a full height, full width compartment.

The DAB vehicles were built to an overall length of about 8.7 metres, with axles at the extreme front and rear. This gave a very long wheelbase, 6,350 mm, but completely flat floor for passengers. The height of the floor was only 230 mm above the ground, and this could further reduced by kneeling the suspension. Despite the long wheel base, the DAB vehicles are quite manoeuvrable. Some are providing inter-terminal services at Copenhagen Airport. They are ideal for airline passengers with heavy baggage, but cope well with busy and restricted roads.

Neoplan

Think of innovation and Neoplan will always be there. Like DAB, they put the power pack in the N4114-DE model at the extreme rear. A 6.87 litre MAN engine provided power to a Magnet Motor generator, and from there to wheel hub motors by the same company on the rear axle. This bus was built to a overall length of very nearly 12 meters, with the front axle set back behind the entrance. The two wheel boxes were the only intrusion in a otherwise totally flat floor.

The Neoplan vehicle had a very long wheelbase, approximately 8.65 metres, but this was compensated by enabling the rear axle to steer at low speeds. This has helped the bus to negotiate tight turns which might otherwise have been beyond its capability. Neoplan has also been involved in several other hybrid bus projects, including versions of its mid-sized Metroliner-in-Carbon and, more recently, vehicles powered by fuel cells, last year, Neoplan delivered a fleet of low floor articulated buses to the Swiss city of Lausanne. They could operate either like a trolley bus, taking power from overhead wires, or off-wire, with a large Mercedes Benz diesel engine powering a generator.

In the mid 1990's both Voith and ZF developed wheel hub motors which could be used in conjunction with hybrid drive systems. Mercedes Benz built a

fleet of articulated buses for the city of Stuttgart. In retrospect, ZF and Voith both spend considerable sums on technology which was rapidly overtaken.

The Volvo ECB

Towards the end of 1995, Volvo unveiled its remarkable Environmental Concept Bus. This was not intended for production, but was a fully operational vehicle with a number of advanced ideas which could in future be incorporated in production buses.

The Volvo ECB had an overall length of 10.7 metres, with the axles at the extreme front and rear. The hybrid driveline was particularly ingenious. A gas-turbine engine was mounted at roof level, but very neatly concealed. It was coupled to a high speed generator which produced electric power. That in turn drove an electric motor fitted to the rear axle, or could be used to recharge lightweight nickel metal hybrid batteries, also mounted in the roof. The Swedes have shown considerable interest in ethanol as an alternative fuel. That was used in the ECB, resulting in a 90% reduction in nitrous oxide emissions. However, the engine could be adjusted to run on various other kinds of fuel.

Last year, two full size, low floor Volvo B10L city buses entered service in Gothenburg on extended trials. They have gas turbine engines, fuelled by ethanol, located in the normal engine compartment. The engines generate electricity and drive to ABB electric motors and the standard portal rear axle. Volvo says that the emission levels are only a tenth of those of the proposed Euro 5 standard.

Mercedes Benz Cito

Mercedes Benz has now teamed up with Siemens on hybrid technology. They started later than, but they have since come up on the rails and gone into a firm lead, in terms of numbers delivered. The Cito is very advanced minibus, available in optional lengths of 8, 8.9 and 9.6 meters. This vehicle has its front axle in the conventional position, behind the driver's compartment and front entrance. The rear axle is at the extreme rear, beneath a full height and full width compartment. Currently the Cito is powered by a 4.25 litre diesel engine, which can be specified to Euro 3 emissions levels. It is mounted quite high in the compartment and delivers power to a Siemens generator, which is a standard unit currently, used in trains and robotic systems. Power is taken from a generator through a converter to an electric drive motor, which delivers power directly to a standard Mercedes-Benz rear axle through a reduction gearbox.

There is neither a gearbox or a mechanical linkage between the engine and the rear axle. There are no banks of batteries in the Cito. The batteries are the same size as a standard diesel bus. Therefore, there is a significant saving in weight and cost.

On the Cito there is enough space in the rear compartment to fit a fuel cell power system at some stage in the future. Mercedes Benz has already announced plans to build up to thirty full size city buses with fuel cell power units and to sell them to selected operators in 2002, to give them practical experience of the new technology. That would tend to indicate that the fuel cell would be a regular production option by the middle of this decade, in the Cito and full size buses. The Cito is built in a separate facility within the huge Mercedes Benz factory at Mannheim. It has a single shift capacity of over 300 units per annum. Already, over 200 have been delivered. France has the largest number including 17 in Marseilles and 12 each in Toulouse and Rheims. There are about 60 operating in Germany, including a fleet of 18 at Expo 2000 in Hanover. Whereas other Mercedes Benz buses are steel framed, the Cito makes extensive use of Alusuisse sections.

The Cito is built to an overall width of 2.35 metres, which makes it easier to drive in narrow streets in old city centres. Acceleration is jerk free. The brake pedal is linked to an electric braking resistor which acts like a retarder. This brings the bus to a halt very gently. This smoothness of drive is an important point on a bus where a large percentage of the passengers are likely to be standing.

Italian interest

The Italian market has shown strong interest in hybrid buses, particularly in the centres of some of the oldest cities. There is also quite a revival in trolley buses. In the last year or so, Autodromo, BredaMenarinibus and Cacciamali have all shown hybrid options. This has generally been on mid-sized buses. Italian operators, like those in the United Kingdom, tend to buy quite a variety of sizes and lengths of buses. The streets in the centres of some of the oldest cities are simply incapable of taking full size single deckers.

Irisbus and Alstom

Irisbus is a major party along with Alstom and Michelin in the very advanced CIVIS and Cristalis project. These advanced vehicles are described by their makers as rubber tyred on-street public transport. They are pitched somewhere between buses and trams.

Orders have been placed by several French cities, and also by Las Vegas. Some models will be all electric, but other will be diesel electric and therefore hybrid. Alstom supplies the complete electrical system, including alternator, inverter, control units and the wheel hub motors. These fit inside super single wheels and tyres, which have been specially developed by Michelin. Like the Cito, the Alstom system does not need banks of batteries.

Indian experience with Ashok Leyland

In India the Hybrid Electric Bus have been developed by Ashok Leyland in collaboration with several other partners. The HE bus is being viewed in India as the eco-friendly option for cities where CNG is not available. This is a series Hybrid Electric Vehicle powered by a downsized diesel engine (with lower power) and a battery pack. The diesel engine, operating at an optimal, constant speed, drives a generator which supplies power to an AC induction motor through vector controlled drive, to propel the vehicle. An electronic controller constantly monitors the load requirements from the battery and the generator; the generator output is adjusted accordingly. Extra power, when required, is drawn from the battery pack. When the vehicle is decelerating, the batteries get charged by the induction motor. The batteries can also be charged from mains during overnight parking.

This Hybrid Electric Vehicle is a shining example of partnership between the Government and the private sector. It is the result of joint development work by Ashok Leyland, the Department of Scientific and Industrial Research (DSIR) and the Electronics Research and Development Centre, Trivandrum (ER&DCI) of the Ministry of Information Technology (MIT).

Hybrid electric three wheelers

Essentially, three wheeled motor scooters with room for three passengers and a driver, auto-rickshaws can be found across Southeast Asia and India. TVS Motor Company, Ltd has turned to hybrid electric drive technology to make help cut down on air pollution by creating a vehicle that more closely matches the needs of congested Asian streets from Delhi to Bangkok. The company has introduced its new concept auto-rickshaw based on charge sustaining, parallel hybrid electric vehicle technology.

The heart of the hybrid drive is a 8 hp, four-stroke internal combustion engine. The electrical system developed by Solectria consists of a 1 kW DC motor operating in parallel mode with the engine. The vehicle operates as a battery EV up to 10 Km/h speed when the engine cuts in and takes over. The

motor then acts as a generator and charges three maintenance free 12V VRLA batteries. At higher speeds or gradients, the system acts in a power assist mode. During braking and coasting energy is recovered in a regenerative mode, which is shut off if the batteries reach full charge. The top speed of the vehicle with power assist is about 65 Km/h, which is a practical speed for Indian cities. The control system works in conjunction with a human interface, which operates the pedal systems. An unusual feature of the vehicle is that charge sustaining parallel operation is achieved with a carburettor-controlled engine and not an electronic Engine Management System. This was done to keep costs low.

The system is configured for operation in crowded Asian cities, characterized by frequent stops, traffic movement in stop-go mode with extensive braking and occasional clear stretches of road. Such conditions are tailor-made for hybrid electric vehicles.

TVS has carried out a number of simulation studies of different configurations using the NREL Advisor package. The system was configured to demonstrate the feasibility of making a viable charge sustaining parallel hybrid electric small vehicle with an internal combustion engine, which does not depend on the power grid. Significant savings in fuel and reduction in emissions are expected from the vehicle.

Policy Implications

Properly designed HEVs can offer substantial social benefits in terms of reduced emissions and improved fuel efficiency. This can be achieved by; Plugging HEV into the electric utility, like battery operated EVs and thereby displacing fuels with utility electricity.

HEVs offer the performance, range and “full tank” feeling of security that drivers now have in conventional vehicles, while the relatively small, low-cost battery packs of an HEV may make HEVs more affordable than their battery operated EV counterparts.

The HEVs thus, may broaden the markets beyond the market that exists for EVs. This large market would enable large economies of scale, higher production levels and lower per vehicle costs for both HEVs and EVs. The results could be a greater market penetration with correspondingly greater benefits (e.g., reduced emissions, reduced fuel use and increased use of electricity) than would be possible with EVs alone. For these reasons, regulations, R & D initiatives and financial incentives should be consistent with these benefits in order that a “level-playing field” be created for all alternative

vehicle fuel systems. In so doing, regulators can assist the introduction of HEVs by recognizing their social benefits in vehicle regulations.

International status on promotion of HEVs

Because HEV is a relatively new technology and costs more than similar equipped gasoline powered vehicles several supporting measure are required to promote the sales of this type of vehicles. Thus, financing as expected is a central issue in any effort to acquire and use alternate fuel vehicles such as hybrid electric vehicle.

United States of America

The Internal Revenue Service of US government has determined that gasoline/ electric hybrid vehicles are eligible for "Clean Fuel" vehicle tax deduction of up to US\$ 2000.

Federal Tax Deduction

This is a deduction for the clean fuel vehicle property portion of a vehicle and certain refueling properties. A tax deduction for the purchase of a new original equipment manufacturer (OEM) qualified clean fuel vehicle.

- A tax deduction is available for businesses or people who purchase clean fuel vehicles (other than electric vehicles) and certain refueling property. The deductions are based on gross vehicle weight and type of vehicle according to the Table 5.7. The deduction must be taken in the year the vehicle is acquired. The equipment must be used in a trade or business. After the year 2001, the tax deduction will be reduced by 25% each year until phased out. The current clean fuel vehicle tax deduction is scheduled to be phased out in 2004–2006.

Table 5.7 Tax deduction for purchase of clean vehicles in USA

Vehicle type	Capacity/ Gross Vehicle Weight	Tax deduction (US\$)
Truck or van	(10,000-26,000 lbs)	5,000
Truck or van	(greater than 26,000 lbs)	50,000
Buses	(seating capacity of 20+ adults)	50,000
All other vehicles	----	2,000

State and Alternative Fuel Provider Fleets Program

EPAct established the State and Alternative Fuel Provider Program which is a DOE regulatory program that requires covered state and alternative fuel provider fleets to purchase AFVs as a portion of their annual light duty vehicle acquisitions. Fleets earn credits for each vehicle purchased and credits earned in excess of their requirements can be banked or traded with other fleets. This gives fleets a lot of flexibility in meeting their requirements.

Japan

This subsidy system in Japan aims to promote the introduction of EVs and HEVs with lightening financial burden of users, accelerate the reduction of vehicle costs, and trigger the diffusion of EVs and HEVs. The Japanese government has adopted incentives related to HEV's in 1999. A low emissions vehicle receives an Automobile Acquisition Tax cut of 2.7% and a hybrid vehicle receives a break of 2.2%. The purchase of efficient vehicles is further encouraged by removing \$3,000 from the purchase price of the vehicle before calculating the acquisition tax. Finally, if vehicles such as trucks and buses conform to the strict NOX emissions standards, the acquisition tax is reduced by 1.2%. Tokyo has additional tax breaks for more environmentally friendly vehicles, like hybrids (Environment Agency web site 2000). The various incentives for producers and consumers of HEVs provide strong structural reasons why Japanese automakers are leading in hybrid development.

Fuel Cells

A fuel cell is an energy conversion device that converts the chemical energy of a fuel such as hydrogen, into electricity by an electrochemical process. The construction of a fuel cell is similar to the battery and includes anode, cathode,

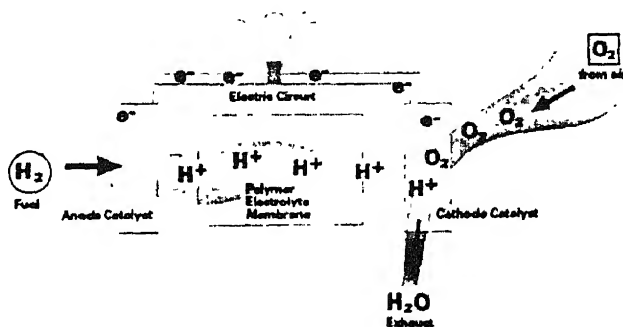


Figure 5.4 Working principle of a fuel cell

electrolyte and current collectors. The fuel (hydrogen) is fed to the anode and reacts with anode catalyst structure to generate protons and electrons (Figure 5.4). The protons flow through the electrolyte layers and combine with oxygen on the cathode side to form water with the help of a cathode catalyst. The electrons flow from the anode through an external load to the cathode to create electricity. As long as the reactants *pure hydrogen* and *oxygen* are supplied to the fuel cell, it will produce electrical energy.

Features of fuel cells

A factor that draws interest to the fuel cell is that it can operate at efficiencies two to three times that of the internal combustion engine, and it requires no moving parts. Since it converts the fuel, hydrogen, and oxygen directly to electrical energy, the only by-products are heat and water. Without combustion, fuel cells are virtually pollution free. Another advantage of fuel cells is that their efficiency increases at part load conditions, unlike gas and steam turbines. Finally fuel cells can use many different fuel such as natural gas, liquefied petroleum gas, biogas, gasoline, diesel, naphtha, methanol and hydrogen. This versatility ensures that fuel cells will not become obsolete due to unavailability of certain fuels.

Advantages of fuel cells

- High efficiency
- Low chemical, acoustic and thermal emissions
- Siting flexibility
- Reliability
- Low maintenance
- Excellent part load performance
- Modularity

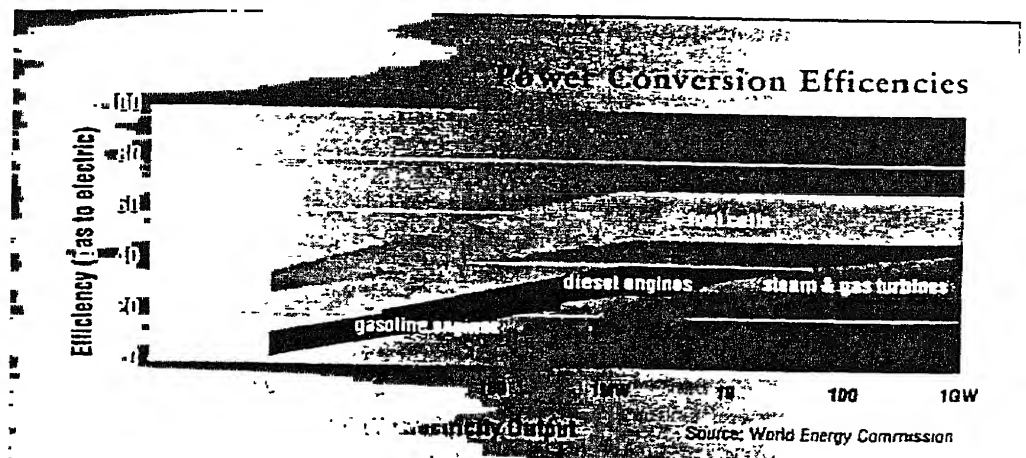


Figure 5.5 Power conversion efficiencies of fuel cells in comparison with Conventional generation systems

Fuel cell stacks

A single fuel cell will produce less than one volt of electric potential. To produce higher voltages fuel cells are stacked on top of each other and connected in series. As illustrated in Figure 5.6, cell stacks consists of repeating fuel cell units, each comprised of anode, cathode electrolyte, and a bipolar separator plate. The number of cells in a stack depends on the desired power output and individual cell performance; stack range in size from a few (< 1 kW) to several hundred (250+ kW).

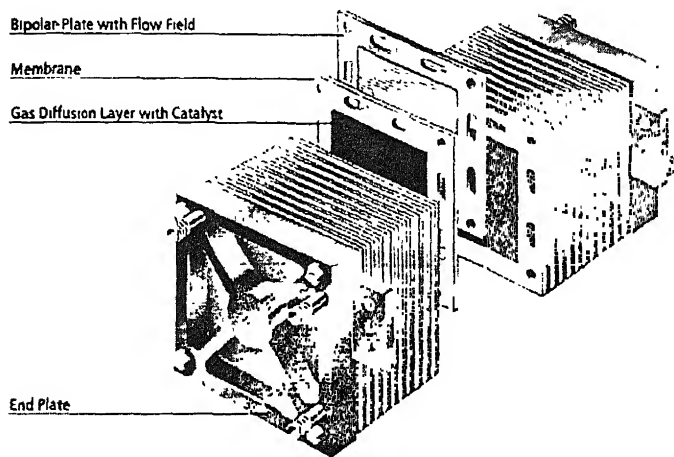


Figure 5.6 Cut section of a fuel cell stack

History of Fuel Cells

In the year 1839, Sir William Grove discovered that it might be possible to generate electricity by reversing the electrolysis of water. In the year 1889, two researchers, Charles Langer and Ludwig Mond, coined the term “fuel cell” as they were trying to engineer the first practical fuel cell using air and coal gas. Further attempts were made thereafter to develop fuel cells that could produce electricity from coal or carbon, however the advent of the internal combustion engine and further technological developments in the ICE technology temporarily quashed hopes of further development of this fledgling technology. Francis Bacon developed the first successful fuel cell device in 1932, this was a hydrogen–oxygen cell using alkaline electrolytes and nickel electrodes. Bacon and his group worked upon improving and scaling up this technology for another two decades and in the year 1959, a practical 5 kW fuel cell system was successfully demonstrated.

In the late 1950s the National Aeronautics and Space Administration (NASA) of US also began to build a compact electricity generator for use on space missions. NASA soon came to fund hundreds of research contracts involving fuel cell technology. Till date fuel cells have been extensively used in space missions and their technical capabilities (except for stray mishaps in the early induction years) have been demonstrated beyond doubt.

In more recent decades, a number of manufacturers including major auto makers and various federal agencies have supported ongoing research into the development of fuel cell technology for use in fuel cell vehicles (FCV) and other applications. Fuel cell energy is now expected to replace traditional power sources in coming years from micro fuel cells to be used in cell phones to high powered fuel cells for stock car racing.

Fuel cell systems

A fuel cell converts the energy of hydrogen into DC electricity. In order to use fuel cells for practical applications the fuel cell has to be coupled with following critical components (Figure 5.7).

- **Fuel processor:** Since hydrogen is not available freely, it has to be extracted from fossil fuels such as gasoline, diesel, methanol, natural gas etc. through a reforming reaction. A fuel processor is a combination of appropriate chemical reactors that convert these fuels into hydrogen rich gases devoid of detrimental impurities.
- **Power conditioner:** this is essentially an inverter in combination with other electronics and converts the DC output of the fuel cell into AC output.

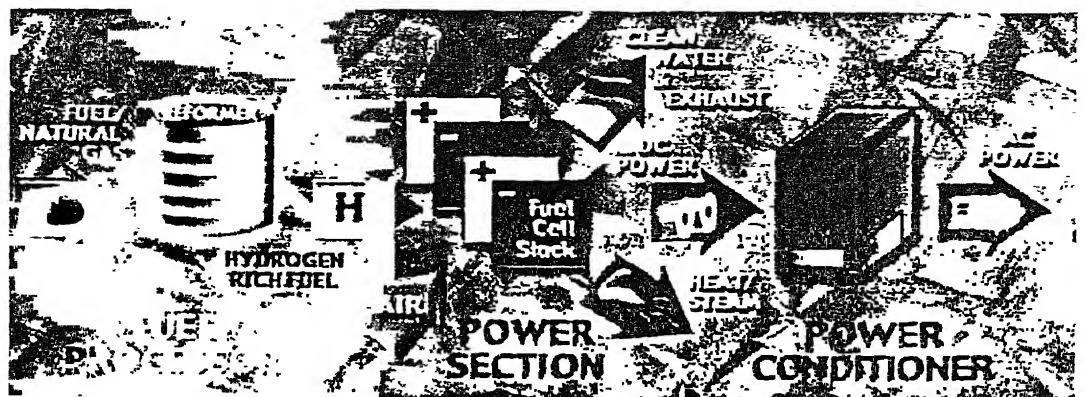


Figure 5.7 Components of a fuel cell system

Types of Fuel Cells

There are various types of fuel cells mainly classified by the type of electrolyte that they use and the operating temperature. These fuel cells are in different stages of development. The operating temperature and useful life of a fuel cell dictate the physicochemical and thermo-mechanical properties of materials used in the cell components (i.e., electrodes, electrolyte, interconnect, current collector, etc.). Aqueous electrolytes are limited to temperatures of about 200 °C or lower because of their high water vapor pressure and/or rapid degradation at higher temperatures. The operating temperature also plays an important role in dictating the type of fuel that can be used in a fuel cell. The low temperature fuel cells with aqueous electrolytes are, in most practical applications, restricted to hydrogen as a fuel. In high temperature fuel cells, CO and even CH₄ can be used because of the inherently rapid electrode kinetics and the lesser need for high catalytic activity at high temperature. The operating temperature, power density and the start-up time also dictate the type of application for which the fuel cell power plant may ultimately be used. For example a low operating temperature, quick start up time and high power density will make a fuel cell power plant more suitable for automotive and portable applications. Whereas a fuel cell with high operating temperature, low power density and delayed start-up time is more suitable for stationary power generation. A higher operating temperature fuel cell technology is also more suitable for cogeneration option as the waste heat can be used in the bottoming cycle for some useful work and thereby enhancing the overall efficiency of the entire fuel cell power plant. The details of the different type of fuel cells and their applications, fuel cell reactions, market segments and status of market readiness are compared in the Table 5.8, Table 5.9, Table 5.10 and Table 5.11.

Fuel cells for automotive traction

For the automotive applications, given the state of the technology, the PEMFC has the best option to replace internal combustion engine for propulsion power. The decision is based on many considerations including the ability to fit size and weight of the power plant under the hood of the car, the ability to start up quickly, the ability to meet the changing power demands (dynamic response) typical in a driving cycle and cost. With the exception of cost PEMFC would meet these requirements today if it could operate on hydrogen. However, the lack of the hydrogen refueling infrastructure, combined with the low energy density (implying a shorter driving range) of today's hydrogen storage technology, the hydrogen fueled vehicle is less attractive to the customers and

thus difficult to sell. The alternative is to carry liquid fuels that have high energy densities and convert them to a hydrogen rich gas (reformat) via an onboard fuel processor, on an as needed basis. As long as the added complexity is transparent to the consumer, this option is still much more marketable. However, the automobile has a limited space, and added weight increases fuel consumption. Furthermore consumer will be reluctant to sacrifice any performance parameters such as the ability to start and drive capability or rapid acceleration. Thus the fuel processor which is now a part of the fuel cell engine, must also meet the requirements of size and weight, be able to start up very quickly, and be dynamically responsive changing power demands, which impose a varying fuel processing rate.

Table 5.8 Fuel cell types and details

Fuel cell	Electrolyte	Fuel	Operative Temperature (°C)	System Efficiency (%)	Power output	Power density kW/m ²	Start-up time
Alkaline (AFC)	<ul style="list-style-type: none"> Diluted potassium hydroxide solution in a porous matrix Mobile Ion OH⁻ 	Hydrogen	150 - 200	40 - 50	0.3 - 5 kW	0.7 - 8.1	Minutes
Polymeric Electrolyte (PEM)	<ul style="list-style-type: none"> Solid Polymer organic, poliperfluorosulfonic acid Mobile Ion H⁺ 	Hydrogen	50 - 120	40 - 50	Few watts - 250 kW	3.8 - 6.5	Seconds minutes
Direct Methanol (DMFC)	<ul style="list-style-type: none"> Solid polymer electrolyte 	Methanol	80 - 140	35 - 40	< 1 kW	-	-
Phosphoric Acid (PAFC)	<ul style="list-style-type: none"> Liquid phosphoric acid contained in a porous matrix Mobile Ion H⁺ 	Hydrogen	175 - 220	40 - 50	40 - 250 kW	0.8 - 1.9	Hours
Molten Carbonate (MCFC)	<ul style="list-style-type: none"> Liquid lithium, sodium, potassium carbonates solution in a matrix Mobile Ion CO₃⁻ 	Hydrogen Natural Gas	600 - 700	>60	100 kW - 25 MW	0.1 - 1.5	Hours
Solid Oxide (SOFC)	<ul style="list-style-type: none"> Zirconia doped with yttria Mobile Ion O⁻ 	Hydrogen Natural Gas	600 - 1000	>60	100 kW - 25 MW	1.5 - 2.6	Hours

Source. filebox.vt.edu/eng/mech/emi/00FCC-10.pdf, as on August 10, 2002

Table 5.9 Fuel cell reactions for different types of fuel cells

Fuel Cell Type	Anode Reaction	Cathode Reaction
Alkaline	$\text{H}_2 + 2\text{OH}^- \rightarrow 2\text{H}_2\text{O} + 2\text{e}^-$	$\frac{1}{2}\text{O}_2 + \text{H}_2\text{O} + 2\text{e}^- \rightarrow 2\text{OH}^-$
Proton Exchange	$\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$	$\frac{1}{2}\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2\text{O}$
Phosphoric Acid	$\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$	$\frac{1}{2}\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2\text{O}$
Molten Carbonate	$\text{H}_2 + \text{CO}_3^{2-} \rightarrow \text{H}_2\text{O} + \text{CO}_2 + 2\text{e}^-$	$\frac{1}{2}\text{O}_2 + \text{CO}_2 + 2\text{e}^- \rightarrow \text{CO}_3^{2-}$
Solid Oxide	$\text{H}_2 + \text{O}^{2-} \rightarrow \text{H}_2\text{O} + 2\text{e}^-$	$\frac{1}{2}\text{O}_2 + 2\text{e}^- \rightarrow \text{O}^{2-}$

Table 5.10 Fuel cell applications

	Fuel cell type					
	AFC*	PEMFC	PAFC	MCFC	SOFC	DMFC†
Rated power level (projected)	10-100 kW	1-1000 kW	100-5000 kW	1000- 100,000 kW	100- 100,000 kW	1-100kW
Market Segments (projected)						
Electric utility			✓	✓		
Remote generation	✓		✓	✓		
Dispersed	✓	✓	✓	✓	✓	
On-site cogeneration		✓	✓	✓	✓	
Automotive	✓	✓	✓			✓
Buses, trucks	✓	✓	✓			
Railway	✓	✓				
Space	✓	✓	✓			
Submersibles		✓				
Portable, commercial	✓					
Portable, military		✓			✓	
Portable, Mining	✓	✓				

Source. "Fuel Cell Systems", Leo J. M. J. Blomen and Michael N. Mugerwa (eds.), Plenum Press, 1993

Table 5.11 Fuel cell technologies and their readiness status

Phosphoric Acid (PAFC)	<ul style="list-style-type: none"> ▪ Premium applications with proven reliability. ▪ Prices are now in the \$3500–4000/kW range. ▪ Current production capacity is 40 MW/year in US/Canada. ▪ The prospects for continued and substantial cost reductions are unlikely due to limited expectations that the power density can be increased. ▪ Optimists hope that costs could decline to \$2000/kW with high production volume.
Alkaline (AFC)	<ul style="list-style-type: none"> ▪ Used in space applications with proven reliability. ▪ Modified systems under development for stationary, marine and transport applications. ▪ Prices currently in the region of \$3,000/kW. ▪ Projected costs are very low due to the potential for non-noble catalysts to be used. ▪ The power density and sensitivity of the AFC to carbon dioxide will limit its use in limited applications. ▪ Current production capacity is 10MW/year in Germany, with further capacity being added in the USA and Russia.
Proton Exchange Membrane (PEMFC)	<ul style="list-style-type: none"> ▪ Poised to attain commercial viability the earliest. ▪ Efficiencies ranging from 24–32% but projected to go to 30–40% when operating on natural gas reformat, and higher on direct hydrogen. ▪ Sizes up to 250 kW being tested, but commercial versions are likely to first appear in sizes up to only 10 kW. ▪ Costs for stationary demonstration units are still above \$10,000/ Kw but are projected to come down to \$700–1500/kW by 2004–2008 with high-volume production. ▪ Current production capacity is 20 MW/year in US/Canada, which is expected to double in the short-term, driven primarily by vehicle markets.
Molten Carbonate (MCFC)	<ul style="list-style-type: none"> ▪ Could become commercial by 2003–2008. ▪ Future units could achieve 55% efficiency (in comparison with today's 47%). ▪ Current costs are \$8000/kW but are dropping and may soon reach half of the current costs. ▪ Expected costs for the 2003–2008 time frame are \$1000–1900/kW in sizes from 250–kW to 3 MW with high volume production. ▪ The 250 to 300 kW size is expected first. ▪ Current production capacity is 10 MW/year in US/Canada.
Solid Oxide (SOFC)	<ul style="list-style-type: none"> ▪ These are attaining 47% efficiency. ▪ Cost still over \$10,000/kW for a 100–kW demonstration version. ▪ In the period 2004–2008, 47–63% efficiencies could be attained at costs from \$800–1500/kW with high volume production. ▪ Current production capacity is 4 MW/year in US/Canada.

* Adapted from . "Market Prospects & Attendant Intervention Strategies to Accelerate the Deployment of Fuel Cells in Distributed Power Generation for Developing Countries", International Finance Corporation, 2001.

Hydrogen

Hydrogen is one of the abundant elements in the universe, but it is highly reactive and does not exist as a gas naturally on earth. Approximately 40 million tons of hydrogen gas is produced globally in a year and a very little of this is used as an energy source. There are several methods for producing hydrogen, however the choice of production methods depends on the quantity and desired purity of hydrogen.

Steam Methane Reforming

Catalytic steam reforming of methane is a well known and commercial process for hydrogen production. Almost 90% of the hydrogen production in the world is being produced by steam methane reforming process.

The first step of this two step process is to expose methane (natural gas) to high temperature steam to produce hydrogen, carbon monoxide, and carbon dioxide. The second step is to convert the carbon monoxide with steam to produce additional hydrogen and carbon dioxide. The yield of hydrogen is approximately 70%–90%. After reforming, the resulting syngas is sent to shift reactors, where the hydrogen output is increased via the water shift gas reaction which converts CO to H₂. The last step in the hydrogen production is the purification process and the degree of purification depends on the application. For PEMFC and PAFC closely coupled to reformers, diluents such as CO₂ and CH₄ are tolerable. However, for use in PEMFC, the CO levels have to be reduced to less than 10 ppm. This is generally accomplished by a preferential oxidation system.

Partial Oxidation

This is another commercially practised process for deriving hydrogen from hydrocarbons. In this process methane (natural gas) or any other hydrocarbon feed stock such as oil is oxidized to produce carbon monoxide and hydrogen. The reaction is exothermic and no indirect heat exchanger is needed. Catalysts are not required because of the high temperature, however the catalyst can be used for enhancing the yield of hydrogen per mole of methane feedstock. A hydrogen plant based on partial oxidation includes a partial oxidation reactor, followed by a shift reactor and hydrogen purification equipment.

The efficiency of the partial oxidation unit is relatively high (70 – 80%), however partial oxidation systems are less energy efficient than SMR because of the high operating temperature as well as due to the problem of heat recovery.

Auto thermal reforming

Autothermal reforming combines the features of steam reforming and partial oxidation systems. In an auto thermal reforming reaction, a hydrocarbon feed (such as natural gas or liquid fuel) is reacted with both steam and air to produce hydrogen rich gas. Both the steam reforming and partial oxidation takes place. With the right kind of input fuel, air and steam, the partial oxidation reaction supplies all the heat needed to drive the catalytic steam reforming reaction. Unlike the SMR, the autothermal reformer requires no external heat source and no indirect heat exchangers. This makes autothermal reformers simpler and compact. In an auto thermal reformer all the heat generated by the partial oxidation reaction is fully utilized to drive the steam reforming reaction. Thus autothermal reformers typically offer higher system efficiency than partial oxidation systems, where excess heat is not easily recovered. As with a steam reformer or partial oxidation system, water gas shift reactors and purification systems are needed.

Methanol Steam Reforming

Methanol is a liquid fuel that can be more easily stored and transported than hydrogen. Because it can be readily steam reformed at moderate temperatures of 250–350 °C, it is being promoted as a possible storage fuel for fuel cell vehicles. Experimental fuel cell vehicles with onboard methanol fuel reformers have been tested by DaimlerChrysler, Toyota and Nissan. Although most of the methanol reforming technologies are being tried for fuel processing onboard the fuel cell vehicles, it has also been suggested that hydrogen might be produced by steam reforming at refueling stations. The reaction takes place in the presence of copper/zinc catalysts in the temperature range 200–350 °C. Overall the reaction is endothermic, requiring the application of heat, through an indirect heat exchanger, to a catalyst filled tube or catalyzed plate.

Electrolysis

Hydrogen can also be produced by the electrolysis of water. The decomposition of water by electrolysis consists of two partial reactions that take place at the two electrodes. The electrodes themselves are separated by an ion containing electrolyte. The energy for electrolysis is supplied in the form of electricity. Water electrolysis in its conventional form, alkaline electrolysis, has been in commercial use for over 80 years. Currently only less than 1% of the hydrogen production world over is being done by water electrolysis.

Because electrolytically produced hydrogen is created indirectly via the energy carrier 'electricity', this process is economically feasible in places where electricity can be extremely cheaply generated. This in turn is generally possible in countries with large scale hydro-system eg Egypt, Iceland, Canada, Norway and Zaire. The electricity can also be cheaply generated in setup with excess energy from the primary and secondary control of existing power station capacity with significant nuclear components such as in the countries like France, Belgium, Switzerland and key electric utilities in Germany.

Table 5.12 Advantages and disadvantages of reformation and electrolysis

Advantages		Disadvantages
▪ Reformation of fossil fuels	▪ Relatively inexpensive hydrogen production method	▪ Nonsustainable
	▪ Well developed technology	▪ Pollution generated in processing
▪ Electrolysis		▪ More expensive and less efficient than direct use of fossil fuels
	▪ Well developed technology	▪ Expensive
	▪ Potential to be sustainable	▪ Pollution possible from electricity generation
	▪ Creates pure hydrogen product	▪ Less efficient use of fossil fuels for electricity production compared to reformation
	▪ Electricity widely available	

Photoelectrolysis

In a one step process, sunlight is absorbed in a semiconductor, splitting water into hydrogen and oxygen. (At present, experience in this process is minimal).

Biomass Gasification and Pyrolysis

Hydrogen is obtained from biomass by forming a gaseous fuel which is subsequently cleaned and reformed. Steam reforming converts the methane to CO and CO₂. Subsequently the CO is converted to hydrogen and CO₂ through shift conversion. Finally the hydrogen is separated typically by pressure swing adsorption. Liquid fuels such as methanol and ethanol can also be obtained from biomass.

There are different techniques for processing biomass and they can be broadly classified as dry chemical process and aqueous process. In the chemical process the biomass is either subjected to Pyrolysis, (where it is distilled in the

absence of oxygen to yield oils/ gas and char) or Gasification in which biomass is partially oxidized at elevated temperatures to generate combustible gas rich in CO₂, hydrogen, and some saturated hydrocarbons primarily methane.

Photobiological

Certain photosynthetic microbes produce H₂ in their metabolic activities using light energy. Employing catalysts and engineered systems, H₂ production efficiency could reach 24%.

Storage

The main options for storing hydrogen are as a compressed gas, as liquid, or combined with a metal hydride. Underground storage is considered, although it is just a special case of compressed storage gas. Each alternative has advantage and disadvantages. For example, liquid hydrogen has the highest storage density of any method, but it requires an insulated storage container and energy intensive liquefaction process (Amos, 1998).

The ability to utilize hydrogen directly in a fuel cell, without an on-board reformation process, is appealing from an efficiency and emission standpoint. However, due to its properties of low energy density volume and boiling point, onboard storage of hydrogen systems tend to be large and heavy. Three types of direct storage systems are available viz, Compressed gaseous hydrogen, Liquefied hydrogen and Binding hydrogen to solids in metal hydrides or carbon compounds. The Table 5.13 compares features of the on board hydrogen storage methods to an energy equivalent amount of gasoline.

Table 5.13 Comparison of On-board Hydrogen Storage Options

	Gasoline	Compressed Hydrogen	Liquefied Hydrogen	Metal Hydride (Ovonics Mg Alloy)
Btu	1,334,540	629,500	629,500	629,500
Fuel weight (Kg)	29.5	4.7	4.7	4.7
Tank Weight (Kg)	13.4	63.3 - 86	18.6	120
Total weight of fuel system (Kg)	43.2	67.9 - 90.5	23.3	124.7
Volume (Liters)	40.1	408.8 - 227.2	177.9	120
Range (km)	600	600	600	570

Source. Future Wheels, 2000

Compressed gas storage tank

New materials have permitted storage tanks to be fabricated that can hold hydrogen at extremely high pressures. At present, the costs of the tanks and compression are high, but the technology is available.

Liquid Hydrogen

Cooling a gas to form liquid does liquefaction. Liquefaction process uses a combination of compressors, heat exchangers, expansion engines, and throttle valves to achieve the desired cooling. Liquefaction of hydrogen takes upto 30% of the energy of the fuel, making the overall storage costs very high.

A major concern in liquid hydrogen storage is minimizing losses from liquid boil-off. Because liquid hydrogen is stored as a cryogenic liquid that is at its boiling point, any heat transfer to the liquid causes some hydrogen to evaporate. Condensing hydrogen gas into the more dense liquid form enables a larger quantity of hydrogen to be stored and transported. However, converting hydrogen gas to liquid hydrogen is costly and requires a large input of energy.

Chemical Hydrides(high and low temperature)

Various pure or alloyed metals can combine with hydrogen, producing stable metal hydrides. The hydrides decompose when heated, releasing the hydrogen. Hydrogen can be stored in the form of a hydride at higher densities than by simple compression. Using this safe and efficient storage system depends on identifying a metal with sufficient adsorption capacity operating under appropriate temperature ranges.

Gas-on-Solid Adsorption

Adsorption of hydrogen molecules on activated charcoal (carbon) can approach the storage density of liquid hydrogen.

Microspheres

Very small glass spheres can hold hydrogen at high pressures, charged with gas at high temperatures where the gas can pass through the glass wall. At low temperatures the glass is impervious to hydrogen and it is locked in. Customized glass spheres are being developed for this purpose.

Hydrogen Activities Internationally

Many countries have Government led hydrogen Programs with perhaps the biggest players being Japan, Canada, US and Germany. In addition to national

initiatives the International Energy Agency co-ordinates a number of international initiatives aimed at improving the understanding of hydrogen and leading towards a hydrogen future (Lakeman & Browning, 2001).

National Programs

Japan

Japan has the largest and most wide ranging of the national hydrogen programs. The WE-Net (World Energy Network) project operates as part of the New Sunshine project. This New Sunshine project resulted from two older projects. The “Sunshine” project, started in 1974 to investigate new energy concepts and the “Moonlight” project, which started in 1978 to investigate energy saving technologies. Hydrogen and fuel cells were previously covered under both programs. Both these programs were combined in 1993 to form the New Sunshine Programs. The New Sunshine project has been allocated approximately £7.6 Billion (US\$11 B) over its 28 year lifetime. Of this some £1.4 Billion (US\$2 B) are intended for use in the We-Net project, directly administered by the New Energy and Industrial Technology Development Organization (NEDO). The We- Net project is divided into three stages and is expected to continue till 2020.

USA

The US has a very large hydrogen programme which has managed to increase its budget even in the face of general energy funding cuts. It is however uncertain whether this will continue under the new presidency. The DOE Hydrogen Programme also had a budget of £17 M (US\$ 24.5) M) in 2000 and has requested £16 M (US\$23 M) for 2001. If all related projects such as fuel cells are included, it is estimated that US funding on hydrogen and fuel cell research exceeded £83 M (US\$ 120 M) in 2000.

The Hydrogen Programme is part of the Office of Power Delivery Systems within the Office of Power Technologies (OPT), which is in turn within the Office of Energy Efficiency and Renewable Energy. The programme includes three focus areas :

- Research and Development of Critical Component Technologies (production, storage, and utilisation),
- Technology Validation
- Analysis and Outreach.

Germany

Germany has shown a strong commitment to hydrogen especially for its use in transportation. Government and company funding has been directed towards promoting hydrogen technologies. In part this is due to Germany's dependence on imported oil. However, funding for hydrogen research from the German Federal Ministry for Education and Research (BMBF) has decreased continuously during the last several years. Hydrogen funding in Germany had its peak in 1991 (DM 17 Million) and has decreased by a factor of almost 20 since to current levels of DM 1 Million. However, fuel cell funding has fared better with a peak in funding of about DM 17 Million in 1995. This was followed by a gradual decrease in funding by 30% to DM 13 Million in 1999. However, fuel cell funding back to the 1995 levels of DM 17 Million have been announced for this year.

Research funding of the last several years concentrated on electrolyzers, hydrogen automobile demonstrations, and the use of hydrogen in energy generation including the generation of electricity by fuel cells, heat production in boilers and catalytic heating systems and cold generation in catalytic cooling systems. Future research will focus mostly on fuel cells and electrolyzers with particular emphasis on cost reduction of these technologies.

Canada

Canada has a large hydrogen programme, especially in relation to its size of population. The Canadian national Hydrogen R&D Programme (CNHP) is administered by the federal government. The goal of the Programme is to develop and to evaluate hydrogen systems for both stationary and transport applications. Current funding is about £0.9 M (Can\$2 M), and this funding is allocated to establishments that have co-funding from industry. Canadian technologies are funded wherever possible, but foreign technologies are also considered where they integrate with the objective of the Programme. A number of Canadian provinces also have regional hydrogen Programmes notably British Columbia (BC), Quebec, Ontario and Alberta.

Iceland

According to the Kyoto agreement Iceland can increase its CO₂ emissions by 10% from 1990 levels. However, Iceland has negotiated to erect new power-intensive metals industries that will increase the emissions by more than 10%. All of Iceland's space heating is now geothermal and all electricity production is hydro or geothermal. As there is no CO₂ burden associated with either of these

energy sources, the only way to reduce CO₂ emissions is by reducing the usage of fossil fuels. A new company, Icelandic New Energy Ltd., has been set up as a joint-venture company, owned by VistOrka hf (meaning EcoEnergy), Norsk Hydro ASA, Daimler Chrysler AG and Shell Hydrogen BV, with the aim of replacing fossil fuel use in Iceland with hydrogen, underpinned by the island's substantial geothermal and hydro resource. Iceland has targeted 2030 for the full implementation of the hydrogen economy.

Iceland provides an ideal environment for a hydrogen energy project as the concept enjoys the support of government and public, and the technology will be subjected to the demands of a western technological society. Furthermore, the Icelandic climate will test the ability of new technology to operate in severed conditions of weather and operating environment. As the country's population is only 260,000, a "real-scale" project is feasible.

Iceland's CO₂ emissions are divided roughly equally between the transport, fishing and industrial sectors. Conversion of the transport and fishing fleet to operation on hydrogen would therefore cut the country's anthropogenic CO₂ emissions by 66%. The transition would occur over a 30–40 year timescale beginning with a demonstration project using hydrogen buses in Reykjavik and ending with the conversion of the fishing fleet. Principal problems to be overcome are the limitations of current on-board hydrogen storage options for vehicles, and the development of MW scale fuel cells and related storage facilities needed to operate fishing vessels for extended periods at sea.

United Arab Emirates

It is interesting that even the oil producing countries are now starting to show an interest in hydrogen and that Dubai and United Arab Emirates is investigating the feasibility of hydrogen production in collaboration with BMW. They are particularly interested in solar hydrogen production because of the large amount of sunshine the area receives.

Norway

Norway has funded a feasibility study into hydrogen as a future energy carrier. The project was conducted by the Foundation for Scientific and industrial research at the Norwegian Institute of Technology (SINTEF), the Norwegian University of Science and Technology (NTNU), the Institute of Energy Research (IFE) and the University of Oslo (UiO). The report recommended a research Programme should be funded by the Norwegian government with a budget of

NOK 30 to 40 Million per annum over 5 years. It remains to be seen whether such a Programme will be adopted by Norway.

Italy

AEM SpA, the municipal energy company of Milan, Italy, and the German car manufacturer BMW announced in arch 2001 the plan of building jointly the first Italian hydrogen filling station. The filling station is to be erected in the technology zone "Bicocca" near Milan on the 1.3 MW PAFC demonstration plant site, already authorised for hydrogen production and handling. The plant, including a natural gas reformer, concluded a first phase of experimental operation from 1995 to 1998. At that site AEM, and the affiliate Zincar Srl, will produce hydrogen through natural gas reforming for mobile applications, in collaboration with ENEA (the national agency for energy and environment) or another partner. The hydrogen will be used partly for demonstrations of public transport vehicles and the rest will be supplied to a stationary 500 kW MCFC plant. The project is also expected to provide more experience with the reformer and CO₂ sequestration and storage.

Other countries with hydrogen projects / programmes include : France, China, Argentina, Canary Islands, Spain, Switzerland, Croatia, Armenia, Brazil, Egypt and Cuba.

International Programmes

International Energy Agency (IEA)

The IEA is responsible for administering the hydrogen Implementing agreement one of the many that come under the renewable energy sector of the IEA. The agreement is intended to promote technical exchanges between member countries and encourage task sharing.

The IEA was established in 1974, with the initiation of the Hydrogen Programme in 1977 to deal with every aspect of hydrogen technology. It was decided at the outset that a long-term programme was required in order to realise the potential of hydrogen and since then nine specific tasks have been completed. These have dealt with particular aspects of hydrogen technology, such as thermo-chemical and electrolytic production methods, and results have been presented in a series of annual reports.

European Union

The European Integrated Hydrogen Project (EIHP) is now in its second phase (2001-2004). The project has a budget of ECU 4.9 Million, of which 50% is provided by the EU and consists of 20 industrial partners.

The aim of this project is to develop a refuelling station layout requirement, analyse and quantify health, environment and safety risks associated with on site hydrogen equipment. The project will identify the requirements necessary to harmonise standard, codes of practice and filling procedures applicable to refuelling station sub-systems and components on a global and European level. This will include the refuelling interface (nozzle-receptacle) between the filling station and the vehicle. The outcome shall be approved refuelling connectors. EIHP will undertake comparative risk and safety analyses with respect to the release of hydrogen in confined and semi-confined environments (tunnels inner-city streets and garages). It is envisaged that the experimental data will provide sufficient input to allow the definition of hydrogen related standards and regulations. EIHP will attempt to co-ordinate such activities between the EU and USA.

The Fifth Framework Programme promotes hydrogen-related activities, although not specifically mentioned. This follows the policy of the Commission to orientate and fund research according to broad objectives. Hence, hydrogen research is integrated in the wider context of the main thematic lines of the different work programmes. In the programme "Energy, environment and sustainable development" (ENERGIE), activities are focused on the generation of electricity and / or heat, with reduced CO₂ emissions, from biomass or other fuels. The programme will also include the development demonstration and integration of new and renewable energy sources, particularly fuel cells, into energy systems.

In the programme "Competitive and sustainable growth", activities concerned with hydrogen storage and use are targeted. In particular, R&D work on the optimisation of production and pre-treatment of nano-tubes, or other caged molecules, is funded.

Moreover, as a broader issue for transportation, research is focused on the technological development and demonstration activities, which would lead to validated, advanced concepts for sustainable mobility and improved safety, while reducing the environmental impact. Items such as guidelines, safety standards, licensing procedures will also supported.

Over the last ten years or so, the Commission has invested ECU 92 Million in part funding 135 collaborative hydrogen projects.

Euro-Quebec Hydro-Hydrogen Pilot Project (EQHHPP)

In 1998, the European Commission and the government of Quebec came to an agreement to investigate jointly the perspectives of renewably produced hydrogen as clean fuel. The project was to be carried out by European and Canadian industrial companies and research organisations. In a detailed feasibility study between 1989 and 1991 (EQHHPP Phase II) it was investigated whether 140 MW of surplus electricity produced in existing hydropower plants (which could not be fed into the existing electric grid) could be converted into hydrogen, transported to Europe and applied there in various end-use technologies. By 1991 the general feasibility could be proven with a 15% cost accuracy. In 1992 the general feasibility could be proven with a 15% cost accuracy. In 1992, an additional investigation phase looking at various scientific and technological questions, as well as on approval issues concerning the delivery of liquid hydrogen to the port of Hamburg, was carried out. In parallel, a financial engineering phase took part during 1991 and 1992. During this phase it turned out that the required funding of approximately £0.7 Billion (US\$1 Billion) could not be raised in a joint effort by the participating industry, national governments and the European Commission.

Therefore, on recommendation by the European Parliament, the focus was shifted to the development, realisation, testing and demonstration of key hydrogen application and infrastructure technologies, such as buses, aircraft jet engine, transport containers and co-generation units. The demonstration phases III.0-2 (1992–1995), III.0-3 (1993–1998) and III.0-4 (1994–1998) have generated plentiful experience and technological improvement in the field of hydrogen energy. In the 10 year project duration a total budget of approximately £11.8 Million (ECU 18.7 M) or a minimum of 37% were funded by the EU.

Under this project, about thirty European industry / research centres / universities have been involved, working on a comprehensive set of hydrogen application / uses. Public transportation means (city buses, boats) equipped with internal combustion engines (ICE) or fuel cells and using either liquid or compressed hydrogen have been demonstrated. Co-generation (CHP) projects based on the use of phosphoric acid fuel cells (PAFC) were realised. In joint co-operation, aviation combustor test activities have been carried out by Daimler Benz Aerospace, Airbus Industries and Pratt and Whitney. Investigation of hydrogen storage in zeolites, carbon and nano-tubes started. Tests on

compressed hydrogen gas storage tanks were also conducted. The projects have now terminated.

United Nations Development Program

- The governing body of the United Nations Global Environment Facility (GEF) has given the go-ahead for a demonstration project to demonstrate fuel cell buses in 5 developing countries. These are the developing countries where the existing public transportation system is a proven source of toxic emissions. It is expected that between 40 and 50 fuel cell buses will be delivered and deployed at a total cost of £90 Million (\$130 M), between 2002 and 2003, to major cities and capitals with some of the worst air pollution levels in Brazil, Mexico, Egypt, India and China.

Fuel Cells in Passenger Cars^a

U.S. and Canada

Ballard Power Systems

Ballard is the leading supplier of PEM fuel cells for transportation. The company has received orders from auto manufacturers around the world. Ballard has introduced the Mark 902, its most advanced fuel cell platform to date. The Mark 902 establishes a new standard of performance by optimising lower cost, design for volume manufacture, reliability, power density and compatibility with customer system requirements. Ballard, DaimlerChrysler and Ford Motor Company have signed an agreement in which Ballard will acquire the interests of DaimlerChrysler and Ford in XCELLSIS GmbH and Ecostar Electric Drive Systems, LLC. This transaction increases DaimlerChrysler and Ford's commitment to, and reliance on, Ballard as their exclusive fuel cell engine supplier. Ballard unveiled its latest fuel cell stack, the Mark 900. This stack uses low-cost materials and is designed for high volume manufacture.

Chrysler (DaimlerChrysler)

DaimlerChrysler has unveiled a fuel cell powered Town & Country minivan, the "Natrium", which uses Millennium Cell's Hydrogen on Demand system. The unique feature of the Natrium is that the hydrogen for the fuel cell is generated from sodium borohydride, which is derived from borax. Chrysler has unveiled the second fuel cell concept vehicle based on the Jeep Commander, running on hydrogen reformed on-board from methanol. The vehicle is actually a fuel cell/battery hybrid concept, with a nickel metal hydride battery to provide

^a Source : www.fuelcells.org/ as on 10th September 2002

supplemental energy during acceleration, and for cold starts. The battery also captures energy from regenerative braking. The hybrid powertrain gives the Commander 2 near-zero tailpipe emissions, while achieving double the fuel efficiency of a conventional SUV.

Energy Partners

Energy Partners (EP) is one of four fuel cell "engine" companies participating in the DOE funded program. EP claims the first fuel cell passenger car, a demonstration sports car called the "Green Car." EP developed a demonstration fuel cell utility vehicle based on John Deere's "Gator" vehicles. The company has conducted interesting work on low cost fuel cell components.

Ford Motor Corporation

A group of Ford Motor Company engineers, scientists and marketing specialists recently set a national endurance record with Ford's P2000 fuel cell vehicle. Ford broke the U.S. record for fuel cell endurance during a 24-hour test. The P2000 maintained an average on track speed of 65 mph and an average overall speed of 57.95 mph. Over the course of the 24-hour test, the vehicle traveled 1390.75 miles further than any other fuel cell vehicle has traveled in a single day. Ford unveiled the TH!NK FC5, a family size sedan powered by a Ballard fuel cell electric powertrain using methanol fuel. Based on the 2000 Ford Focus, the TH!NK FC5's fuel cell powertrain is located beneath the vehicle floor, so it doesn't compromise passenger or cargo space. Ford's P2000 Prodigy is a fuel cell powered sedan, running on stored hydrogen. It is designed to achieve the same performance as Ford's Taurus, with a fuel cell engine that achieves the equivalent of 90 horsepower. Ford also introduced a P2000 SUV concept, a sport utility vehicle that will feature a fuel cell engine with a methanol reformer. Ford and Mobil are collaborating on a fuel processor to extract hydrogen from hydrocarbon fuels for use in fuel cell vehicles.

General Motors

General Motors unveiled the fuel cell AUTOnomy, a platform that looks like a giant skateboard in which the entire propulsion and electrical systems are built into a 6-inch-thick chassis. The chassis, long and flat, could be built in varying lengths and widths to accept a wide array of body types, from family sedan to SUV or from station wagon to hot little sports car. General Motors and Suzuki Motors Corp. are expanding their alliance to cover the development of fuel cell vehicles. The collaboration will focus on developing small-car applications for

fuel cell technology. GM and ChevronTexaco Corp. have formed a pact to speed the pace of introducing gasoline fuel cells in cars, a technology that cuts emissions of greenhouse gas carbon dioxide in half.

General Motors unveiled its prototype, the HydroGen1 fuel cell, its smallest, most powerful fuel cell yet. The HydroGen1 is two-thirds smaller than previous GM models, yet provides 80 kW of power, and has a thermal efficiency of 53 to 67 percent. In addition, the HydroGen1 can start a car in temperatures as low as -40° C. General Motors unveiled the Precept concept car, in both hybrid and fuel cell powered forms. The Precept has a four-wheel drive, dual-axle setup. Electricity from the fuel cell is used to drive the electric motor on the Precept's front axle. Composites of actual data indicate the fuel cell Precept will achieve 108 miles per gallon gas equivalent. GM showed the Opel Zafira fuel cell minivan, powered by its seventh generation fuel cell system. The Zafira was the pace vehicle for the marathon at the 2000 Summer Olympics in Sydney, Australia. GM's Delphi subsidiary is working with ARCO and Exxon to jointly develop on-board fuel processing technology and hardware to convert gasoline to hydrogen for use in PEM fuel cell engines.

H Power

H Power makes PEM fuel cells for a variety of specialty mobile applications. H Power supplied a PEM fuel cell to the Project New Jersey Venturer, a partnership between state government, private industry, and educational institutions. The group built and raced a fuel cell powered car in the 1999 Tour de Sol Road Rally.

Humboldt University/Schatz Energy Research Center

Schatz Energy Research Center (SERC) is researching and developing fuel cells for vehicles, concentrating for now on specialty vehicles and "neighborhood vehicles" which are now street legal in the U.S. In 1998, it unveiled a fuel cell powered version of the Danish Kewet, a two-seat coupe, and supported development of the T-1000 Neighborhood Truck, a half-ton pickup built by Coval H2 Partners and powered by a 6.5kW PEM fuel cell.

IdaTech (formerly Northwest Power Systems)

IdaTech develops and commercializes fuel processors and fuel cell systems. IdaTech tests synthetic diesel and synthetic gasoline as on-board sources of reformed hydrogen to power fuel cells.

Plug Power, L.L.C.

Plug Power L.L.C., along with Arthur D. Little Inc. and Los Alamos National Lab, has successfully demonstrated a fuel cell operating on hydrogen derived from gasoline and is focusing on integrating the system into a vehicle. Plug Power is developing a 50 kW engine for DOE.

UTC Fuel Cells (formerly International Fuel Cells)

United Technologies Corp. (UTC) subsidiary UTC Fuel Cells and Hyundai have worked together to produce four hydrogen powered fuel cell vehicles based on the Santa Fe sport utility vehicle. These zero emission vehicles contain a 75 kW fuel cell system and use a conventional automobile battery for start-up. Enova Systems will supply the electric drive train and power management systems for the vehicles. UTC is working with Toshiba to develop a prototype fuel cell system that extracts hydrogen from gasoline.

UTC, in partnership with the Department of Energy (DOE), has developed a gasoline-powered fuel cell system powerful enough to operate an automobile. The collaboration between DOE and UTC will result in the delivery of the fully integrated 50-kW IFC PEM fuel cell power plant, which incorporates both a fuel processor and cell stack assembly.

Europe

BMW

BMW announced plans to unveil a hydrogen-powered Mini Cooper, featuring an internal combustion engine (ICE) similar to its Clean Energy cars. The Mini Cooper features an advanced hydrogen fuel storage tank that utilizes the same space as a conventional fuel storage tank. BMW and Delphi Automotive unveiled their first development vehicle featuring a solid oxide fuel cell auxiliary power unit (APU). The APU provides sufficient energy for existing mechanically-driven sub-systems, such as the air conditioning and water pumps. The APU could also be used to run devices while the vehicle is idle.

BMW AG plans to fit an unspecified number of 7 Series sedans with fuel cells from UTC Fuel Cells. The vehicle will run on a hydrogen combustion engine; the fuel cell will power the car's on-board electrical system. BMW will develop

hydrogen fuelled FC forklift trucks, deploying about 2,000 in the company's own facilities prior to marketing them to other users.

DaimlerChrysler (formerly Daimler-Benz)

Daimler-Benz began road testing a fuel cell van, NECAR (New Electric Car), in 1993. Daimler has developed and operated four generations of fuel cell passenger vehicles, utilizing a variety of fuels. In November of 2000, DaimlerChrysler presented the NECAR 5, the latest version, in Berlin. The NECAR 5 runs on methanol, unlike its predecessor, the NECAR 4, which ran on hydrogen.

Daimler is part owner of Ballard and partners with Ford in several ventures related to the development and sale of fuel cell vehicles. Daimler has committed \$725 million into its partnership with Ballard and Ford. Daimler presented a fuel cell as a compact auxiliary power unit (APU) in an internal combustion Mercedes-Benz S class model.

De Nora S.p.A.

Italy's De Nora S.p.A works with PEM fuel cells for buses and marine applications. The company spun off its fuel cell R & D unit to form De Nora Fuel Cells. The company is cooperating with Renault and Peugeot/Citroen on fuel cell car projects. De Nora supplied the fuel cell engine demonstrated in the Coval truck.

Fiat

Fiat presented the prototype of its first fuel cell car, Seicento Elettra H2 Fuel Cell. The two-seater car was developed with the support of the Italian Ministry of the Environment and runs on hydrogen.

Peugeot/Citroen

PSA Citroen is working with Renault to speed the development of a commercially viable fuel cell car by 2010. PSA Peugeot/Citroen is leading the HYDRO-GEN project, building a second generation PEMFC car powered by a De Nora stack and compressed hydrogen.

Peugeot/Citroen is involved in a European joint PEM fuel cell program designed to reduce fuel cell system weight and costs.

Renault

Renault SA of France and Nissan Motor Co. have decided to develop cars with a fuel cell that runs on gasoline. The companies will spend \$714 million on the project and will market the fuel cell vehicles as early as 2005. Renault is also working with PSA Citroen to speed the development of a commercially viable fuel cell car by 2010. Renault has designed, built and tested a fuel cell powered Laguna Estate. Renault built its own fuel cell for the car. The FEVER ("Fuel cell Electric Vehicle for Efficiency and Range") is a Renault station wagon powered by a PEM fuel cell engine fueled by stored liquid hydrogen.

Volkswagen/Volvo

Volkswagen introduced its first fuel cell-powered car at the California Fuel Cell Partnership headquarters' opening. The zero emission vehicle (ZEV) is called Bora HyMotion, based on the Jetta. The HyMotion fuel cell engine runs on hydrogen and has a power output of 75 kW. Volkswagen is involved with CAPRI, a project that will deliver a prototype methanol FCV. Ballard will supply the fuel cell and Johnson Matthey a "Hot Spot" reformer. In a joint project, Volvo and Volkswagen have announced plans for a methanol-fueled PEM fuel cell hybrid "Golf" type car.

Xcellsis (formerly dbb fuel cell engines, inc.)

Xcellsis plans to produce 100,000 fuel cell engines a year starting in 2004. Shell Oil has teamed up with Xcellsis to develop the hydrogen infrastructure for fuel cell vehicles. At the same time, the partnership is pursuing technologies to reform gasoline.

ZeVco

London's Westminster City Council has bought a fuel cell van, made by ZeVco, for 33,000 pounds (\$47,000). The vehicle, which will be used in the upkeep of London's parks, has a top speed of 62 mph and is 50 percent cheaper to run than a conventional combustion engine-powered vehicle. ZeVco demonstrated its zero-emission "Millennium Taxi" in New York. ZeVco is the only company pursuing terrestrial development of alkaline fuel cells.

*Asia**Daewoo Motor*

Daewoo Motor has reports that it will embark on a fuel cell research and development program with a state-run laboratory.

Daihatsu

Daihatsu presented the MOVE FCV-K-II, a four-seater fuel cell mini-vehicle that uses a high-pressure hydrogen storage tank system. The MOVE FCV-K-II uses a 30 kW Toyota fuel cell stack, installed beneath the floor at the rear of the vehicle.

Honda

Honda has developed a four-seater fuel cell car, the FCX-V3, which has a motor 25 percent lighter than the two-seater fuel cell car unveiled last year. The car also has a faster start-up time - brought down to 10 seconds from 10 minutes - and uses a newly developed ultra-capacitor instead of a battery, resulting in improved acceleration. The FCX-V3 has been road-tested in the California Fuel Cell Partnership program. Honda introduced two fuel cell cars the FCX-V1 and FCX-V2. The V1 uses a 60kW Ballard PEM fuel cell and runs on hydrogen stored in an "occlusion alloy". The V2 has a 60kW PEM fuel cell built by Honda and utilizes a Honda-built methanol reformer.

Honda plans build 300 fuel cell powered vehicles a year starting in 2003 for sale in Japan and the U.S. Recently FCX – V4 model of Honda with an improved driving range has been introduced in US and the company plans to build about 30 such prototypes and give it on lease to prospective customers.

Hyundai

The Hyundai Santa Fe, powered by a 75-kW PEM fuel cell, scored best in class in two key performance tests at the Michelin Challenge Bibendum, an annual event where new automotive technologies are evaluated by independent judges. The Santa Fe scored an "A" in noise and a "B" in energy efficiency. United Technologies Corp. (UTC) subsidiary UTC Fuel Cells and Hyundai have worked together to produce four hydrogen-powered fuel cell vehicles based on the Santa Fe sport utility vehicle. These zero-emission vehicles contain a 75 kW fuel cell system and use a conventional automobile battery for start-up. Enova Systems will supply the electric drive train and power management systems for the vehicles. Hyundai will use fuel cells in its research and development of fuel cell technology as part of a cooperative program with the Korean government. Hyundai has developed a fuel cell concept car powered by methanol with its affiliate Kia Motors Corp. The hybrid car, a result of a two-year project costing 9 billion won (US\$8,082,000), contains a 10 kW fuel cell.

Mazda

Mazda Motor Corp. plans to start test-runs of its "Premacy FC-EV" car powered by a methanol-reformer fuel cell system and an electric motor in Japan. Mazda aims to start marketing fuel cell cars around 2005, after making alterations to the vehicles based on the results of the test drives. Mazda unveiled a fuel cell concept car, based on its Demio compact, fueled by hydrogen.

Mitsubishi

Mitsubishi plans to have a running prototype FCV with a production model ready in 2005. Nippon Mitsubishi oil is working to produce a liquid fuel that can be used in fuel cells instead of gasoline.

Nissan

Nissan Motor Co. and Renault SA of France have decided to develop cars with a fuel cell that runs on gasoline. The companies will spend \$714 million on the project and will market the fuel cell vehicles as early as 2005. Nissan showcased the new fuel cell-powered electric Xterra SUV at the California Fuel Cell Partnership headquarters' opening. In May Nissan began test drives in Japan of a direct hydrogen fuel cell vehicle equipped with a methanol reformer. The Xterra utilizes this technology as well as a neodymium magnet synchronous traction motor combined with a lithium-ion battery.

Nissan is testing a fuel cell/battery hybrid vehicle. The car, based on the R'nessa sport utility vehicle, features a PEM fuel cell developed by Nissan, a methanol-reformer and lithium-ion batteries. The vehicle is able to switch between a fuel cell-powered driving mode and a battery-powered driving mode. Nissan says it will have a commercial model fuel cell vehicle in 2003.

Nissan and Suzuki have joined a government-sponsored project to develop direct methanol fuel cells for vehicles. The joint project will result in a prototype vehicle by 2003.

Suzuki

Suzuki unveiled a fuel cell powered Covie two-seater at the 2001 Tokyo Motor Show. The vehicle features a General Motors fuel cell stack, and uses natural gas as the fuel.

Toyota

Toyota has demonstrated its new fuel cell hybrid vehicle, the FCHV-4, based on the new Highlander SUV. The vehicle, which Toyota says will be launched on a

limited basis in 2003, will be demonstrated through the automaker's participation in the California Fuel Cell Partnership. Toyota says the vehicle, with a cruising range of more than 155 miles, has "three times the vehicle efficiency of an ordinary gasoline-powered car. " Toyota also unveiled the FCHV-5, which runs on clean hydrocarbons, in Japan.

Toyota has unveiled methanol and hydrogen fuelled versions of its FCEV, based on the RAV4 sport utility vehicle. Both use Toyota's own PEM engines in hybrid configuration. Toyota plans to launch a commercial FCV in 2003. Exxon and Toyota are working on technology to extract hydrogen from gasoline. Toyota has said methanol is the preferred option in the near term.

Fuel Cells in mass transit

Fuel cells are being evaluated or developed for a variety mass transit applications, such as locomotives, transit buses, taxis and in countries like India for three wheeler auto-rickhaws. Most European and North American bus manufacturers are conducting research, demonstrations or evaluations. The R & D has also been initiated in developing countries like China, India, Thailand and Brazil. Essentially all major automobile manufacturers in the world are pursuing fuel cell vehicles, however only few are developing or have plans to develop fuel cell buses. All the developments are based on the PEMFC technology excepting the Georgetown University Bus Demonstration where a PAFC was used as an electricity source. The major manufacturers and the demonstration programs are mentioned in the following section.

Ballard Power Systems

Ballard Power Systems and XCELLSIS Fuel Cell Engines shipped the first bus powered by the pre-commercial fuel cell engine to the SunLine Transit Agency in Palm Springs, CA. The first "real" demonstration vehicle using modern fuel cell technology was a 32-foot bus rolled out in 1993 by Ballard. Three fuel cell buses have just finished demonstration in Chicago, sponsored by the Chicago Transit Authority. Ballard supplied the fuel cell engines, which operate on gaseous hydrogen. A similar pilot fleet project recently finished completion in Vancouver, British Columbia.

DaimlerChrysler

DaimlerChrysler and BP Amoco under joint venture agreement have initiated a demonstration in the London city. BP will fund the cost of developing the

hydrogen fuel infrastructure and Daimler will provide three hydrogen powered Citaro buses in 2003.

DaimlerChrysler's "New Electric Bus," or NEBUS, has completed regular service on a special line in Hamburg city center to demonstrate its performance in real life service conditions to Hamburger Hochbahn AG. DaimlerChrysler is also road testing the NEBUS in Stuttgart, Germany. The first prototype commercial versions of NEBUS are expected to be available for fleet testing within a year. Demonstrations are being considered for Mexico and Brazil.

DaimlerChrysler plans to build 20 to 30 fuel cell city buses within the next three years and sell them to transport operating companies in Europe and abroad. The fuel cell "Citaros" are expected to be delivered by the end of 2002, at a price of US\$1.2 million each. The buses will run on compressed gaseous hydrogen, with a top speed of 50 mph (80 kmph) and a range of 186 miles (300 km).

Georgetown University

Georgetown University introduced a "commercially-viable" fuel cell powered transit bus in May 1998. The bus uses a 100kW phosphoric acid fuel cell engine from UTC Fuel Cells, and is methanol fueled with a 350-mile range. In March 2000, Georgetown University unveiled its second 40-foot, fuel cell-powered transit bus on campus, made possible through a program with the Federal Transit Administration. The bus has a Novabus RTS platform, a Lockheed Martin Control Systems electric drive, a vehicle system controller by Booz-Allen and Hamilton and a 100kW PEM fuel cell developed by XCELLSIS.

H-Power

H-Power was the system integrator in the original DOE/Georgetown program and now makes PEM fuel cells for a variety of specialty mobile applications.

MAN

MAN demonstrated a 12-meter, low floor transit bus powered by a 120kW 400 V Siemens/KWU PEM fuel cell. Hydrogen is stored on the roof of the bus, holding a total volume of 1548 liters, which lasts over 250 km (156 miles). Following more testing, the bus will be used in public transit service in late 2000 in the cities of Nuernberg and Erlangen. MAN is planning on a second-generation of liquid hydrogen powered buses, to be demonstrated in 2001 in Berlin, Lisbon and Copenhagen.

Neoplan

Neoplan launched their first fuel cell bus in October of 1999. The standard 8-metre bus is powered by a 50kW DeNora PEMFC with battery to provide total power of 150kW, and fueled with compressed hydrogen. Neoplan and Proton Motor Fuel Cell GmbH displayed a hybrid PEM fuel cell bus at Munich's "Fuel Cell Day" in May 2000. The bus contained a 400 V, 80kW PEM fuel cell system. Extra energy for acceleration and hill climb is provided by a 100kW flywheel system.

Renault V.I.

Renault V.I. and Iveco plan to begin road testing a 60 kW hydrogen fuel cell bus in the Northern Italian city of Torino in June of 2001. The project is dually financed by the private and public sectors, and depending on results, might lead to the purchase of more zero emission vehicles during the latter half of the decade.

SunLine Services Group

SunLine Services Group, in the city of Palm Desert, operates a fleet of fuel cell vehicles, and is the site of a hydrogen dispensing station. Over the next two years, the fleet will include two hythane (mix of compressed natural gas and hydrogen) buses and one PEM fuel cell bus. SunLine will also be working with Coval H2 to convert an electric transit bus to a hybrid with the installation of a PEM fuel cell as a range extender. SunLine will eventually purchase five fuel cell buses in 2002/2003 with a \$2 million Federal Transit Authority grant, and has received a bus powered by Ballard Power Systems and XCELLSIS Fuel Cell Engines' pre-commercial fuel cell engine in September 2000.

Thor Industries

Thor Industries will build commercially viable, fuel cell powered, zero emissions transit buses in an alliance with UTC Fuel Cells and ISE Research. The first bus will be built by mid 2001. Thor has exclusive rights for use of IFC's fuel cells in the complete drive system, called Thunder Power, for all North American mid-sized buses. ISE Research will provide its hybrid system and perform the fuel cells systems integration. The U.S. Department of Transportation has committed \$740,000 to ThunderPower towards the development of a 30-foot hydrogen fuel cell transit bus.

Toyota

Toyota Motor Corp. has developed a 63-seater fuel cell hybrid bus with Hino Motors, Ltd. The low-floor city bus, called the FCHV-BUS1, carries high-pressure tanks of hydrogen to fuel the fuel cell engine.

UTC Fuel Cells

UTC Fuel Cells has demonstrated a highly compact, 50kW PEM fuel cell system running on hydrogen and ambient air. UTC also developed a 100kW PAFC for powering the second generation transit bus for Georgetown University's program.

Chapter summary

- Considerable progress has been done in the development and demonstration of electric vehicles at national and international levels. Several countries, including those in Europe, North America, Asia and Australia have initiated programs on promoting electric vehicles for urban transport. The Governments in these countries are providing several incentives including subsidies, tax benefits etc. This apart, the wider acceptance of the electric vehicles for routine transport may have to face practical difficulties, mainly pertaining to shorter driving range, long recharge time and limited battery life.
- In India, the relevance of electric vehicles will be more appropriate because of growing concern about the deteriorating ambient air quality levels mainly caused by the vehicular pollution. The EVs in India could be excellent mode of transport for public fleet vehicles. But because of the inherent limitations of EVs as mentioned above, their use will probably be restricted to specific areas where there are serious concerns about the air quality levels. These areas, for instance could be in crowded routes of metropolitan cities, world heritage sites, like Taj in Agra and of course at places like National Zoo, Trade Promotion Campuses etc. A public fleet of EVs will be more practical since centralised infrastructure for battery recharging can be provided at minimum costs as also the training of the drivers could be addressed in convenient mode.
- For personal EVs, several issues such as comforts of journey, the driving range, availability of recharging facility and above all availability of electricity at recharging point will be crucial factors for commercialising efforts in India. Even with all available incentive and related promotional efforts it is expected that usage of personal EVs will be mainly restricted to

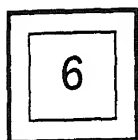
affluent customers in urban areas. As also observed in the developed countries, the customers always chose to own an EV as their second car and almost all the customers opted to own an ICE based car as their first car because it is more reliable and has the requisite driving comforts.

- In order to promote EVs Government agencies have to take appropriate steps to define reserved zone where only zero emission vehicles can ply. This will encourage the customers and public fleet owners to invest in EVs.
- Hybrid electric vehicle technology seeks to address some of technical difficulties faced by the EV technology and the issues of emission and efficiency from a pure ICE vehicle. The electric drive train of HEV derives traction power from combination of a battery and generator coupled internal combustion engine. The HEV technology tends to become more complex as more controls have to be incorporated in vehicle system to synchronise the contribution of ICE and on-board battery for traction purposes. However the total vehicle comfort provided by this technology is a key to wide scale acceptance by customers. This is more so evident by the fact that since its introduction in 1997 and till March 2002, Toyota has close to 1,00,000 HEVs sold in the international market.
- In India, the hybrid electric bus has already been developed by Ashok Leyland. The first prototype of the bus was flagged off in New Delhi at recently held Auto – Expo 2002. The hybrid electric bus could provide an alternate to CNG buses in Indian cities where NG gas is not available. On similar lines the hybrid three wheeler auto-rickshaws have also been introduced by TVS Motor Company. These HEVs are certainly expensive than their ICE engine based counterparts, however appropriate incentives need to be assessed so that the bus and three wheeler operators are encouraged to invest in buying such vehicles.
- HEV will be a more practical approach than EVs in moving to lower emission vehicle regime. The present fuel infrastructure can be availed to its best in an HEV and at the same time it aids in reducing emissions as the vehicle engine could be downsized as compared to pure ICE vehicle. In the long term the internal combustion engine in an HEV will be replaced by a fuel cell engine there by converting the vehicle into a complete zero emission vehicle.
- The fuel cell technology is receiving wide scale attention at international levels. The developed world is viewing fuel cell power plant as an alternate to internal combustion engine for automotive traction. All major automobile manufacturers have ongoing plan for developing fuel cell vehicles and most

of these plans have reached beyond prototype testing stage. Companies like Honda, GM, Ford and Toyota have all developed fuel cell cars and are evaluating the performance under adverse driving conditions to gain relevant data.

- The polymer electrolyte membrane fuel cell technology is gaining wide scale acceptance as on-board power plant for fuel cell vehicles. This fuel cell also known as PEMFC provide quick start up, has low operating temperature and has the highest power density amongst all the fuel cell family members. The biggest disadvantage of PEMFC is that it is very sensitive to CO impurity.
- The biggest hurdle in promoting fuel cell vehicle is the problem of storing fuel on-board the vehicle and providing fuel distribution infrastructure. The present options for on-board fuel storage include storing hydrogen on-board the vehicle or storing liquid fuel such as methanol/ gasoline/ diesel/ethanol and then process it on-board to generate hydrogen. While on-board hydrogen storage is the option of choice, it has problems related to safety, driving range, and of course of creating fuel distribution and refueling infrastructure. In case of liquid fuels, though infrastructure for distribution and refueling is available, the on-board reforming of such fuels is a complex process and has certain limitations in terms of conversion efficiencies.
- The fuel cell systems are also plagued by a high capital cost that has direct impact on the cost of the fuel cell vehicles. It has been evaluated by several manufacturers that for the fuel cell vehicles to be competitive with their ICE counterparts, the fuel cell system costs have to drop to \$ 50 – 60/ kW from the present \$ 3000 – 5000/ kW.
- The use of hydrogen as an alternate to fossil fuels is getting widespread attention in the world. Several countries have initiated hydrogen energy programs with a view to achieve shift from current fossil fuel based generation. Innovative and renewable routes of generating hydrogen for energy generation are being attempted under these programs. Even countries like United Arab Emirates have initiated a hydrogen energy program.
- The validity of fuel cell technology for stationary generation and automotive application is certainly worth studying. The mandate for total zero emission vehicle could only be fulfilled by either electric vehicles or hydrogen based fuel cell vehicles. The present levels of development indicate that in the long term fuel cell technology will emerge as the technology of choice for automotive traction.

- UNDP – GEF has sanctioned \$ 12.1 million project for demonstrating fuel cell buses in a Metropolitan City of India to develop operational experience on hydrogen fuel based fuel cell buses. It is being envisaged that this project will help in reaching the thresholds of the fuel cell bus commercialisation process by way of encouraging interested stakeholder in indigenous development of fuel cell vehicle technology.
- The relevance of fuel cell technology, fuel cell vehicles and the associated issues like fuel production, distribution and refueling options in the Indian context, will be discussed in the final report.



Emission control technologies

There are different types of emissions from different types of engines, which use different kinds of fuels. The main types of engines discussed here are the Combustion Ignition engines (diesel engines) and Spark Ignition engines (gasoline, CNG and LPG engines). The types of pollutants from these engines are very different in terms of their chemical composition and also in terms of the effect that they have on the ambient air quality in turn their effect on human health. The pollutants are mainly divided into two main classes:

- Regulated emissions
- Unregulated emissions.

The regulated emissions in India are given below:

1. Carbon Monoxide (CO)
2. Hydrocarbons (HC)
3. Nitrogen Oxides (NO_x)
4. Particulate Matter (PM)

While all emissions given above are regulated for diesel engines, PM emissions are not regulated for gasoline engines in India.

It is important to note that there has been significant leapfrogging on the issue of automobile technologies and emissions regulations in India in the last 5 – 6 years. The primary reasons for this being the competition induced in the automobile sector with the entry of many multinational automobile companies and the growing concern over the pollution from automobiles. Similar strides would be seen in the emissions regulations also with the growing concern on automobile pollution and could lead to newer emission norms covering wider aspects than the four regulated pollutants mentioned above.

There are many toxic emissions, which are not regulated in many countries including India but form an important aspect of the research work on understanding the effect of these pollutants on human health. A few of the unregulated pollutants from vehicle engines of all types:

1. Formaldehyde and Acetaldehyde
2. 1,3 Butadiene etc.
3. Benzene

4. Poly Aromatic Hydrocarbons (PAH)
5. Particle size and numbers.
6. Composition of the particulate matter

Though there are no measures being taken in India towards establishing norms for the unregulated emissions listed above, they would increasingly become important as significant importance is being given to these emissions internationally.

The reduction of the regulated emissions from both types of engines has been the main focus of all the development work in the automobile technology area. In recent times, in addition to the regulated emissions, the unregulated pollutants have also received focus due to their adverse effect on human health. Many fuel quality changes have also been done with such reductions in focus.

Reducing these emissions has brought about many changes in the basic engine design also which greatly reduced the engine out emissions, but reaching emissions levels of the future like EURO IV in Europe by 2005 or the 2007 US (which almost represent “zero” emissions) emissions regulations would require post-combustion emission control devices also. The various developments in the engine design from the emissions control point of view has been dealt with briefly in the next section.

This section would primarily focus on the post-combustion emission control technologies, which are used with both types of engines for reduction of the regulated pollutants. Almost all technologies available and commercialised today is based on the oxidation properties of the Platinum group metals (PGM) like Platinum, Rhodium and Palladium. Hence it is important to note that almost all these options are very cost intensive due to the high costs of these PGM. Technology development in this area with technologies not using PGM would be very critical for the future emission control technologies. Technologies using molecular sieve technologies in Zeolites like ZSM-5 are under various stages of development to reduce the cost of the after-treatment. This section deals with details on the current after-treatment technologies using catalyst technologies, which are already commercialised and will in due course try to identify catalyst technologies, which are in the development stage. The chapter has been divided mainly into two sections as follows:

- Diesel Emission Control
- Spark Ignition Engine Emission Control

The focus in each section is on the relevant pollutants and technologies to treat them after combustion is completed.

Diesel emission control

Diesel emission control has been the focus area of research since many years due to its increasing use due to higher efficiency. Nitrogen Oxide (NO_x) and Particulate Matter (PM) are the most critical pollutants from diesel engines, which again have a significant impact on human health.

All the regulated emissions for diesel engines are being made increasingly stringent. The emissions regulations are dealt with in the section on emissions regulations review in various countries.

For diesel engines it is important to note that due to high-pressure combustion, combustion efficiencies are significantly higher than the spark ignition engines and use of lean mixtures further improves this efficiency. A result of this is the low level of CO and HC emissions from diesel engines when compared to the spark ignition engines, which are the major advantages of diesel engines.

This section hence focuses on the reduction of the main pollutants from diesel engines which are PM and NO_x emissions.

The types of after-treatment devices, which are used, are given below:

- Diesel Oxidation Catalysts
- Diesel Particulate Filters
- Diesel NO_x Control Technologies

It is important to understand the nature and composition of the diesel particulate matter in order to understand its effect on human health and further its reduction. This will be dealt with in some detail in subsequent sections.

Diesel oxidation catalysts

These are two-way catalysts, which are primarily used to reduce CO and HC emissions from diesel engines. The NO_x emissions from diesel engines are very high relative to the spark ignition engines and hence three-way catalysts are not developed. Also, the catalysts that are used for oxidation are not capable of reducing the NO_x emissions significantly due to the higher engine out NO_x emissions and different formulations are required. The two-way catalysts are already commercialised and are already in use in some categories of vehicles in India also. The diesel oxidation catalyst also reduces particulate matter in the exhaust gases by about 25 – 30 % as the diesel oxidation catalysts oxidise the soluble organic fraction (SOF) of the particulate matter. The SOF is about 25 – 40 % of the particulate matter emissions from the diesel engines. (Tanaka, 1998)

The diesel oxidation catalysts can be used with the diesel quality standards (diesel with max 500-ppm S) currently sold in the cities of Delhi, Mumbai, Kolkatta and Chennai.

The catalysts used in the diesel oxidation catalysts mainly comprise of Platinum or Rhodium. There can be a combination of these two noble metals. There are many design considerations that should be carefully studied before using this technology. There would be some loss of engine power due to the fitment of a device on the exhaust pipe which would restrict the flow of exhaust gases, hence the design of the hydraulics of the exhaust gas flow through the device should be such that this power loss is minimised. This is done by having a substrate (the base on which the precious metal is present as active sites) which has a higher open surface area to reduce restrictions to flow of the exhaust gases. Optimisation needs to be done based on the efficiency required, cells (active sites) per unit area of substrate, precious metal quantity, in order to minimise the cost of the device.

The PM reduction is in the range of 20 – 50 % (average of about 30 % can be considered as practically possible), CO and HC reduction efficiencies are at high levels of 90 %. (www.dieselnet.com/mdec/1999/mckinnon.pdf, August 25th 2002)

Since the PM reduction is only in the range of about 30 % of current levels of particulate emissions, these devices will not be useful to reach very low PM levels of 0.01 g/bhp-hr (2007 US PM and EURO IV emissions regulation. The SOF fraction which mainly comprises of the PAH and un-burnt fuel of the PM will be oxidised in a diesel oxidation catalyst (Lox, 1991). Reaching these levels of PM will require other technologies to achieve these levels of PM regulations. Very active catalysts with high levels of sulphur in the diesel fuel used could result in the increase in the PM emissions as sulphate emissions increases with the formation of sulphate from SO₂ emissions in the diesel exhaust, thereby competing with the reactions of reduction of CO and HC.

Diesel Particulate Filters

Nature of Diesel Particulates

To understand the technologies that are available to reduce particulate matter it is important first to understand the composition of the particulate matter. Diesel particulates are a complex, dynamic “system” comprising carbon soot remnants from the combustion process, ash particles from the lubricating oils, sulfates from the lubrication oil (lubes) and fuels, and unburned hydrocarbons. In the size range which would interest all health experts, generally less than 100 nm

(nanometer). Whilst all regulations have thus far been for the mass emissions of PM_{10} , which means particulate matter below size range of 10micrometer, with increasing concern over respirable PM of size less than 2.5 ($PM_{2.5}$) micrometer is also very important (Timothy V Johnson, 2001). After the formation of these diesel particulates after the combustion process in the diesel engines, there are many mechanisms, which take place, which are very critical in terms of the impact on ambient air quality. These particulates then undergo mechanisms like nucleation and growth, which affect their size and concentration. The properties of these nano-particles vary with time, temperature and also with dilution ratios in air. The various components of the particulate matter are described in some detail in the section below:

1. Carbon Soot
2. Sulphates and Nitrates
3. Soluble Organic Fraction (SOF), fuel and lubricating oil derived.

Carbon Soot

The start of the particulate generation is in the combustion chamber. It is important to note that the fuel composition has a very significant impact on the engine out particulate emissions. Components of diesel like PolyAromatic Hydrocabons (PAH) and the bigger molecules in diesel are instrumental in the generation of PM. This has led to the reducing the PAH content in diesel and also decreasing the T95 point of diesel in future fuel quality standards. The carbon soot is a major part of the PM emissions and its reduction is a very critical part of the overall PM reduction process.

Sulfates, Soluble Organic Fraction (SOF) and Nanoparticle Nucleation and Growth

The sulfates are formed in the PM due to the sulphur present in the fuel and also lubricating oils. With the drastic reduction in the sulphur levels of fuels in order, the reasons for which are explained later on, the sulfate component of the PM has significantly reduced.

SOF is formed due to the unburnt fuel and also lubricating oil. Some partially volatile compounds also form a part of the SOF fraction of the PM.

The nucleation and growth phenomena of the PM are dependent on many factors namely, time, temperature and also the soot concentration as already stated above.

On the regulation front though current regulations are only on the particulate mass emissions on an engine dynamometer, in future the number

and size of particulate matter could also be an area of focus due to the strong health linkages. Many studies are being done to study the size range of the diesel particulate matter and also relate to their health effects and comparing these emissions with emissions from alternate fuels. This will increasingly become important from the policy direction also with proven technologies available to analyse the size ranges of the particulate matter from engines.

Diesel Particulate Filtration

The EURO IV emissions regulations for diesel engines, both light and heavy duty will require advanced emission control technology. These technologies will need to be integrated with technologies required for reducing NO_x emissions, which will be discussed later on in this chapter. These technologies will also be in focus from the retrofit point of view in order to reduce emissions from in-use vehicles.

These devices are also referred to as particulate traps and perform the following basic functions in the order given below:

- Collection of PM, usually on a ceramic filter or similar such filter media.
- Regeneration of filter or burning of soot collected in the filter by various mechanisms.

The regeneration step is the most critical part of the process and there are a variety of methods available for this process and some of the common methods are given below:

- Use of catalyst coated on the filter element to reduce the temperature of combustion of the collected soot particles on the filter.
- Use of a NO_x conversion catalyst upstream of the filter to facilitate oxidation of NO to NO₂, which adsorbs on the collected particulate and substantially reducing the temperature, required to regenerate the filter.
- Using fuel-borne catalysts to reduce the temperature required for ignition of the accumulated material.
- Using electric heating or combustion of atomised fuel by catalyst to heat the incoming exhaust gas to a temperature sufficient to ignite the fuel.

There are precious metal catalysts used for this purpose but the problem with these catalysts is their high sensitivity to sulphur. Sulphur dioxide emissions, which are formed due to the combustion process and from the sulphur in fuel and lube oils, are oxidized by these catalysts to sulfates and this could lead to increase in PM emissions and also deactivate the catalysts. The

result of this has been the reduction in the fuel sulphur levels which in addition to reducing PM emissions, also ensure that these catalysts are active. The effect of fuel sulphur on the performance of the catalysed diesel particulate filters have been extensively studied (Timothy V Johnson, 2001). This paper clearly establishes the relation between the performance of DPF-based devices, which use NO₂ to burn the PM at low temperatures.

Balance Point Temperatures (BPT)

This is the most critical parameter of the functioning of the PM filter. This will determine the extent of regeneration and its efficiency. This is defined as the temperature at which the particulate accumulation on the filter equals the particulate oxidation or burning off, wherein there would be no increase in backpressure and thus the system is in “balance”. The BPT depends on many factors like, flow rate, PM composition, NO_x levels, NO_x/PM ratio, sulphur levels, soot loading rate etc.

The most crucial aspect of this process is that any accumulation of soot due to improper regeneration will lead to increase in the backpressure on the engine and this situation is very dangerous in terms of the effect on the engine and related systems.

All research is concentrated on reducing the BPT of filter systems to ensure proper regeneration of the filters in conditions that are observed in city driving cycles. Apart from the various fuel and engine related factors which the BPT depends on, the regeneration catalyst formulation can significantly affect the BPT. Oxidising NO_x to NO₂ reduces the Balance Point Temperature requirement. NO₂ is a strong oxidising agent for soot. With increasing energy efficiencies from diesel engines with the use of turbochargers, EGR which utilise the heat and pressure of the exhaust gases, exhaust temperatures will continuously decrease hence proper regenerating temperatures and strategies for low temperature regeneration are very important for the future.

Devices that are currently produced comprise of oxidation catalysts, which oxidise NO to NO₂, and then NO₂ in turn oxidises the soot particles. Some of the processes which catalyse these reactions are also patented by Johnson Matthey whose Continuously Regenerating Technology has already reached full commercialisation level and is widely being used as a retrofit in heavy-duty diesel engine applications.

These technologies are patented and are commercialised in US. The requirement of very low levels of sulphur (less than 50-ppm S) is a major impediment to the development of these technologies. Hence technologies

which are less sensitive on the fuel sulphur should be the focus of future emissions reduction technologies. In this area, the technology of fuel borne catalysts, which are not extremely sensitive to fuel sulphur content, is a technology, which require increased attention.

The light-off temperatures of the filter regeneration are very important for determining the BPT of the filter. The light-off temperatures would depend upon the regeneration mechanism that is used.

Fuel Borne Catalysts (FBC) for Filter Regeneration

This regeneration technology has been discussed in detail because of the potential of this technology to be applicable with diesel fuel with sulphur content even at 500-ppm levels which is a major constraint for the other competing technologies.

A key part of the commercial system is the use of cerium fuel borne catalyst to reduce the regeneration temperature of the soot. There are other such additives, which are in the development stage in addition to cerium like, iron/strontium (Fe/Sr) and platinum/cerium (Pt/Ce) blends. Various reviews (Timothy V Johnson, 2001) have been done to determine the levels of dosage of these additives for achieving proper regeneration. Good regeneration has been achieved even at low levels like 4 ppm of Fe/Sr; successful regeneration is achieved during normal driving. It was also observed that there was no deterioration in filter performance. The Pt/Ce blend at very low levels in fuels, 0.25 ppm and 5 ppm respectively performed well in terms of regeneration performance. A study revealed that a diesel engine running with 368 ppm S fuel showed reduction in PM to the extent of 96 %. The comparison between the different technologies in terms of particulate matter reduction is summarised in table 3.1. Another point to be noted is that fuel economy also improved with the addition of these additives as these additives improve combustion, rather catalyse combustion also thereby improving the fuel efficiency and reduce engine out emissions.

There should be more development in this field as this technology does not require the use of very low sulphur levels in diesel fuel and many studies have actually been done at sulphur levels of 368 ppm in diesel.

Some studies have been done using FBC with an activated (having small amounts of Platinum deposited on the filter) filter with 500 ppm S fuel and the regeneration temperatures were observed to be in the range of 300 – 350 Deg C, also the PM reduction efficiency is about 80 – 90 %. (Richards, 1999).

The criteria for choosing a particular FBC are given below

(www.dieselnet.com/papers/9909rhodia, August 25th 2002):

1. Regeneration temperature is only one criterion: it must be compatible with the range of temperatures that the regeneration assistance strategy can provide without a noticeable deterioration of the fuel economy. The regeneration behavior must protect the filter from thermal excursions or thermal shocks, and the regeneration must be complete and smooth.
2. The concentrated FBC must have a shelf life in terms of stability corresponding to at least 5 years of vehicle usage under rigorous climatic conditions.
3. The FBC should not change any characteristic of the diesel fuel, both chemical and physical characteristic of the fuel.
4. The residues of the FBC should not deposit on or damage injector nozzles, valves, piston rings, or turbocharger blades. Furthermore, they should remain in solid form and not adhere to the combustion chamber over the whole range of temperatures to which they are exposed.
5. The residues of the FBC should not chemically react with the filter material or with the canning components in order to avoid corrosion or any other deterioration of the canned filter. FBC action in the combustion chamber as well as its residues in the filter should not provoke the formation of toxic components in the gaseous phase.

FBC technology will need to be implemented in conjunction with the oil-marketing companies, as they will need to add these additives with the concern being the distribution of this fuel only to those vehicles having filters for PM. Currently the distribution of these FBC is being done in a fashion lubricating oils are distributed. The cost of 4 – 8-ppm dosage of the FBC with the fuel before injection is about Rs.1.32 /liter (www.cdti.com, August 20th 2002) and in some cases could cost lower than using an ultra low sulphur diesel fuel (less than 50-ppm S diesel) along with a catalysed particulate trap.

To summarise, systems, which have catalysts, have greater efficiency in removing the hydrocarbons and hence achieve better efficiencies of filtration. This is particularly true with the SOF portion of the PM. But in terms of cost of reducing PM from diesel engines to the automobile, oil-marketing and hence the consumers, the FBC could be a very appropriate technology for reducing PM emissions. This technology should be looked at particularly from the point of view of the medium term reduction in particulate matter until the infrastructure for producing and distributing diesel with very low sulphur levels is available.

The filter technology is fairly well established and is already highly commercialised. The critical aspects of the design of the filters being the pore opening and the thermal resistance of the filters due to the high temperatures prevalent in them.

The cost effectiveness for PM reduction for Diesel Particulate Filters is in the range of about \$2500 to \$6000 / metric ton reduction in PM (MECA, 1999). The particulate matter abatement cost is a function of the regeneration technology that has been used in the filter. The cost is higher for those technologies, which are catalyst based. This is very crucial in the context of gaseous fuels having a tremendous advantage technologically for having very low PM emissions. The factor of durability, which means the life of the filter and the maintenance schedule of the filter, are critical parameters, which would also play an important part in determining the cost of the particular PM reduction technology.

This technology appears to be a cost-effective technology and would compete in terms of cost / ton of PM abatement with the other established technologies in future. Tests need to be done in the Indian context with this technology for ascertaining its impact. There are many similar products provided by many leading fuel additive companies like Octel Corporation, Ethyl Corporation and Lubrizol Corporation with Iron, Manganese and Copper based additives respectively for catalysing filter regeneration.

The following tables 6.1 and 6.2 give the typical comparison between the different particulate control technologies (Timothy V Johnson, 2000): In this connection it is important to note that the emission benefits are very closely related to the duty cycles using which these engines are tested. Two results are presented to identify the various technology options for a particular emission reduction requirement.

Table 6.1 Comparison between different particulate control technologies

Technology	Diesel Fuel Sulphur (wt-ppm)	% Reduction from baseline
Baseline (only EGR*)	368	Baseline
Baseline	54	13
Baseline + FBC	368	26
Baseline + FBC + DOC	368	33
Baseline + DPF ⁽¹⁾	368	82
Baseline + CRT (Johnson Matthey)	54	86
Baseline + FBC + DPF ⁽²⁾	368	96

EGR – Exhaust Gas Recirculation – detailed in next section

FBC – Bimetallic Platinum / Cerium Fuel Borne Catalyst

DOC – Diesel Oxidation Catalyst

CRT – Continuously Regenerating Trap (equivalent to DOC + DPF)

DPF ⁽¹⁾ – Catalysed Diesel Particulate Filter

DPF ⁽²⁾ – Uncatalysed Diesel Particulate Filter

Diesel Engine Type – Detroit Diesel Series 60 Engine

The results of another study where similar comparative analysis has been done are presented below (bus experiment in New York using the Central Business District Driving Cycle)
(www.epa.gov/otag/retrofit/documents/ny_crt_presentation.pdf, September 13th 2002):

Table 6.2 Comparison between different diesel emission control technologies on PM₁₀ emissions

Technology	Diesel Fuel Sulphur (wt-ppm)	PM Emissions
OEM Catalytic Muffler*	350	Baseline
OEM catalytic muffler	50	35
OEM + CRT	50	94

*Catalysed Muffler is equivalent to a diesel oxidation catalyst

NO_x Reduction

The EURO IV and 2007 US EPA regulations for heavy-duty emissions regulations have very low NO_x emissions standards. NO_x emissions have been progressively reduced with the growing concern over the ground level ozone formation for which NO_x is a precursor. Unlike in the case of the gasoline three-way catalyst where the CO and HC will react with NO_x to form nitrogen gas in

stoichiometric air/fuel ratios, in lean burn engines the reductants like CO and HC would prefer to react with the excess oxygen rather than the NO_x.

There are many solutions to address this problem. They are summarised below:

1. Exhaust Gas recirculation
2. DeNO_x catalysts
3. Selective Catalytic reduction (SCR)

Exhaust Gas Recirculation (EGR)

This is not an after-treatment technology but is a technology which uses the exhaust gases as part of the fuel / air mixture in order to make the air/fuel mixture more lean and also reduce the temperature of the combustion thereby reducing NO_x emissions. NO_x emissions are reduced at lower combustion temperatures and EGR uses this principle to reduce these emissions.

(CONCAWE, 1999)

NO_x emissions reductions achieved using this technology in some European test cycles is about 30 % for both light and heavy-duty applications. Another development in this technology is cooled EGR which achieves about 45 % reduction in NO_x emissions in heavy-duty applications.

There are some concerns also with EGR, which need to be noted like increase in PM emissions, deposit formation in the intake. These problems are being addressed by using the exhaust stream downstream of the diesel particulate filter so that the PM does not go back to the engine and cause problems with the fuel injection systems by forming additional deposits. There are no concerns about any adverse effect on the engine performance.

DeNO_x Catalysts

This is a well-established technology and is already commercialised in Europe and US. There are two types of these catalysts, the passive and active type. Both types are discussed in some detail in this section.

a) DeNO_x Catalyst (Passive)

This technology can be used both for light and heavy-duty applications. The technology uses the exhaust hydrocarbons as reducing agents to convert the NO_x to nitrogen gas. It is very similar in this aspect to the gasoline three-way catalytic converter, which also uses similar reaction mechanisms to reduce NO_x.

The reduction obtained in the NO_x levels are in the range of about 5 – 20 %.

(11) The main advantage of this technology is the low complexity of implementation and also little or almost no impact on the engine.

There are some disadvantages of this technology which are listed below:

- Low levels of NO_x conversion efficiency due to lower hydrocarbon selectivity.
- The exhaust will have to be enriched with hydrocarbons for improving the conversion efficiency.
- In case of heavy-duty applications, the catalyst is active only above 350 Deg C.
- Also the moisture stability of the catalyst is poor and the catalyst is also sensitive to SO_2 leading to high sulphate formation.
- Low sulphur fuel requirement for better activity of the catalyst.

Effect of the use of these catalysts on fuel consumption is not clear.

The current typical catalyst formulations are given below:

- Platinum / Al_2O_3 for temperature range of 200 to 300 Deg C
- Zeolite based catalysts (Cu/ZSM-5) for temperature greater than 350 Deg C.
- Special oxides of Titanium for temperature range between 300 to 350 Deg C.

In many cases a combination of the low temperature and high temperature catalysts are used for higher conversion efficiency.

For temperatures lower than 150 Deg C, there are no technologies currently available. In cases where such low temperatures exist, a NO_x trap is used which stores NO_x until the temperature reaches 200 Deg C for the reaction to start.

b) DeNO_x Catalyst (Active)

The conversion efficiencies in this case are in the range of 15 to 35 % (11), which is higher than what are observed in the previous case. In this case having an in-cylinder post injection HC enrichment or enrichment in the exhaust enriches the exhaust gases with hydrocarbons. There would be an increase in fuel consumption to the extent of about 1%.

There are some disadvantages of this technology, which need to be noted:

- Narrow temperature range of activity.
- As already pointed out before, there would be a small increase in fuel consumption.
- Slight increase in HC emissions and there could be a need to have an oxidation catalyst to reduce the HC emissions.

- Fuels with low sulphur levels are required in order for reducing sulphate formation on the catalyst.

The catalyst formulations are same as the formulations for the passive type catalyst.

DeNO_x – Selective Catalytic Reduction (SCR)– Urea agent

This technology has received the maximum attention due to the significant reduction potential of NO_x in order to meet the EURO IV emissions regulations. The technology is based on the injection of urea as an aqueous solution into the exhaust gas before the catalyst with an air assisted injection nozzle. The urea reacts with NO_x to form nitrogen gas, water and carbon dioxide. The catalyst is based on metal oxides like Vanadium Pentoxide (V₂O₅), Titanium Dioxide (TiO₂) and Tungsten Trioxide (WO₃). The optimum operating temperature range is 250 to 500 Deg C. The conversion of the catalyst is higher for NO₂ rather than for NO so there is an oxidation catalyst upstream of the SCR catalyst which converts the NO to NO₂. (*Timothy V Johnson, 2001*)

This technology is not yet fully commercialised though there are many technology demonstration projects, which are currently underway in Europe and US. Also the focus of this technology is for heavy-duty applications rather than light-duty applications.

The LEV II and EURO V legislation in 2007/08 require a high conversion level of nitrogen oxides to meet the emission standards for diesel trucks and other diesel vehicles. Therefore, the US and European heavy-duty diesel engine manufacturers are considering the introduction of urea SCR systems no later than 2005. The catalysts used currently in the SCR systems are based mainly on systems derived from stationary power plant applications for nitrogen oxide reduction. New catalysts are being developed for achieving high conversion levels for nitrogen oxides. Synthetic zeolite based catalysts (molecular sieves) are the latest developments in this field. (*Gieshoff, 2001*)

The main advantages of this technology are given below:

- High conversion efficiency of about 60 to 90 %.
- Will help in heavy-duty engine compliance with EURO IV norms.
- No increase in PM emissions unlike the technologies which have been described before.
- There are studies, which suggest sulphur tolerance of this technology, though all current test and demonstration projects are with very low sulphur diesel.

This technology also has some disadvantages, which are important from the commercialisation viewpoint.

- Urea injection equipment and tank for urea storage.
- Possible slip of ammonia with exhaust gases which would require another oxidation catalyst downstream to contain ammonia slip.
- Infrastructure will be required for refilling urea in the urea tanks of the vehicles.
- Though the SCR catalyst is not sensitive to sulphur, a reversible ammonia-sulphate formation at high levels of sulphur in diesel would require the use of low sulphur fuels to avoid the formation of sulphates in the SCR catalyst.

There will be no perceived impact on fuel consumption directly. Due to the packaging problems and high costs, this technology can be used mainly for heavy-duty applications and its use in light-duty applications will not gain ground due to the high cost of the technology.

The following Table 6.3 compares the reduction in NO_x from a baseline using the technologies stated above (CONCAWE, 1999).

Table 6.3 Comparison between different NO_x reduction technologies

Technology	Fuel Sulphur level (max wt-ppm)	% reduction from baseline
Exhaust Gas Recirculation (EGR)*	No limit on fuel sulphur	30 - 45 %
DeNO _x catalyst (Passive)	500	5 - 20 %
DeNO _x Catalyst (Active)	500	15 - 35 %
Selective Catalytic reduction (SCR)	50 (even less for more reduction)	60 - 90 %

*EGR can be used in conjunction with any of the other three technologies stated above to get a combined effect of more reduction in NO_x.

Gasoline and other spark ignition engine emission control

The critical pollutants from spark ignition engines, which are mainly gasoline engines, are very different in terms of their chemical composition to the pollutants from the diesel engines. CNG and LPG also are fuels of the same category and their combustion follows the same principle as gasoline engines. This section deals with in detail the developments in the field of after-treatment technologies for spark ignition engines. The focus is mainly on the catalysts that are being used.

The various changes in the fuel specifications that have been made progressively reduce the engine out emissions while increasing the efficiency of combustion in the spark ignition engines.

The initial developments in these catalyst systems were to reduce CO and HC emissions by using “two-way” catalysts. Later on the technology upgradation also reduced NO_x emissions and led to the most widely used catalyst systems called the “three-way” catalysts. While the two-way catalysts reduce the CO and HC emissions from the spark-ignition engines, the three-way catalysts also reduce NO_x emissions from these engines. The HC is used to react with the in the presence of the catalyst to reduce NO_x.

Recent developments in catalysts use the HC emissions in order to reduce the NO_x emissions from these engines
(www.mitsubishi.motors.co.jp/GDI2000/p14.html, August 30th 2002). Sulphates do reduce some activity of these catalysts and hence the future fuel standards have low levels of sulphur.

A very important aspect with gasoline and spark ignition engines is the reduction of cold start emissions. Technology improvements in this field have been concentrated on this aspect of emissions also.

Developments in noble metal catalysts

The most critical aspect of the reduction of emissions from gasoline engines is the use of the appropriate catalyst, which will not only give maximum efficiency in terms of reduction of the emissions, but also be a cost-effective choice. The focus of this section is to highlight the developments taking place in this field, in light of the above constraints.

The main noble metals, which are used in these catalysts, are Platinum, Rhodium and Palladium. The common combination used is Platinum in combination with Rhodium. Some studies have revealed that in order to reach “ultra low level emissions” (ULEV) from gasoline vehicles, Palladium catalysts exhibit better performance in terms of lower light-off temperatures which will help reducing cold start emissions also. But the light-off temperature is not only dependent on the catalyst but also on some other factors like the heat transfer rate from the exhaust gases to the catalyst and substrate. Use of ceramic substrates slows down this process. The development of alternate catalyst / substrate technology to increase the rate of heat transfer and also increase catalyst activity could result in significant advancements in achieving emissions levels matching “ULEV” standards. (University of California, 1998).

The advantages of using Palladium catalysts are given below:

- Improved emissions for same precious metal cost compared to platinum containing catalysts, about 25 % in total hydrocarbon emissions, 30 % in CO emissions and 22 % in NO_x emissions.
- Higher thermal stability enabling the use as close coupled catalysts.
- Faster light off times.
- Sulphur tolerance same as Pt/Rh catalysts over short-term operation and more tolerance over a long-term operation, which is a very important factor in terms of the durability which will directly affect the long-term cost.

There are further developments in this field to improve conversion efficiency like increasing the Rhodium content of the catalyst formulation, doubling the Platinum content.

In order to increase the temperature levels to achieve higher conversions, the three-way catalysts are placed closer to the exhaust manifold. This gives faster light off and particularly low HC emissions. But it is also important to note that there would be problems of durability of the catalyst due to the exposure of the catalyst to higher temperatures. Palladium containing catalysts, which have higher thermal stability, are used to address the problem of durability as this is the major advantage of the Palladium catalysts over the other noble metal catalysts.

Gaseous fuels and catalyst temperature tolerance

In this context it is to be noted that in case of engines using gaseous fuels like CNG and LPG, the combustion temperatures are significantly higher than the temperatures observed in the gasoline engines. The higher combustion temperatures result in higher temperatures observed in the catalysts. This would lead to deactivation of the catalyst. The catalyst choice for these applications is hence a challenge. Also, unburned gas in the presence of catalyst would further oxidise and increase the temperatures in the catalyst further. This is an important aspect to be considered during design of emission control devices for these applications as the emissions from these engines could deteriorate with the loss of activity in the catalyst. Many users of the gaseous fuel engines for heavy-duty applications have made these observations.

Sulphur tolerance of catalysts

Another issue where development work is underway is the sulphur tolerance of the catalyst systems especially in the case of gasoline engines. This is not an issue in the case of the CNG and LPG engines as they are fuels with very small

amounts of sulphur. Typically LPG sold in India has a maximum sulphur level of about 20 – 30-ppm max and CNG has sulphur content in the range of about 2 – 3 ppm. The sulphur levels of gasoline will remain high (i.e. at levels of 150-ppm until EURO IV standards are mandated) at levels of about 100 – 130 ppm with the specification for EURO III grade gasoline being 150-ppm max.

With the growing concern of the emissions of the various toxic pollutants apart from the regulated emissions from spark ignition engines, the catalyst efficiency will be very critical for reducing these emissions. This is also important from the growing importance that is being given to the reduction of many unregulated toxic emissions.

Exhaust gas recirculation for NO_x reduction in gasoline engines

Exhaust gas recirculation is also used for gasoline and is similar to the EGR for diesel engines. While close to 45 % reduction in NO_x emissions can be achieved (CONCAWE, 1999), there are some problems with this technology, which are listed below:

- Extra hardware required
- EGR valve can get blocked with exhaust gas deposits resulting in lower exhaust gas flows. Increasing use of detergent additives to deal with this problem is a solution.
- Increased engine noise and wear.
- Increased lubricant oil contamination.

This technology is already commercialised and there is no increase in fuel consumption reported by the use of this technology.

Improving catalyst performance using on-board diagnostics

The performance of these three-way catalytic converters is being further improved with on-board diagnostics (OBD). OBD helps to ensure that a vehicle's emission control devices are kept in good condition. The instrumentation on the vehicles will provide valuable feedback to automobile manufacturers, which can be used to improve vehicle and emission control system designs. OBD are designed to detect vehicle malfunctions or deterioration within vehicle emission control and fuel metering system to maintain acceptable emissions performance. OBD systems can reduce lifetime in-use emissions from motor vehicles. Oxygen sensors at the front and the rear of the engine will help in maintaining air/fuel ratios and also the health of the emission control device. Oxygen storing ceria catalysts are also being used to take care of any period of lean operation in the

engine to ensure optimum performance of the emission control device. Developments in this field also will be dealt with in detail in the final report. Installation of OBD in vehicles comes at an additional cost, which will be very critical in terms of the market penetration that it would achieve in a highly competitive market.

Conclusions

Particulate matter emission control technologies

1. The technology option for PM reduction will be based on the level of reduction that is desired.
2. Future focus will be on particulate matter size range and numbers in addition to identification of specific toxic pollutants from diesel engines and technologies for reducing these emissions.
3. In the short term, for immediate reduction in PM emissions from diesel engines, FBC with DPF will be the option, particularly in the context of current sulphur levels in diesel.
4. The long-term strategy will be largely based on EURO IV quality fuel and technologies for reduction of PM to “near” zero levels from current levels.

NOx control technologies

1. The level of emission reduction required will drive the NOx reduction technology option in the case of PM reduction.
2. The sulphur dependence of most of these technologies would be a major constraint on the use of these technologies, till fuel of acceptable sulphur levels are available. The commercialisation of these technologies would hence be dependent on the availability of the appropriate fuel quality.
3. Combination of the technologies named above in addition to the integration with the particulate reduction technology option will be critical for meeting future emission norms.
4. Reaching emissions regulations equivalent of US 2007 regulations would require the use of the SCR Urea based technology whose commercialisation would be very critical.

Spark ignition emission control technologies

1. Sulphur levels in gasoline would be very important in the process of selection of technology for post combustion emission control, particularly with the sulphur tolerance of these technologies a major constraint in their development.

2. Unregulated emissions and their reduction from spark ignition engines is an area getting increased attention due to the related health effects and this should be a major area of focus for future developments.
3. Choice of noble metal for a particular application would be important both in terms of cost and also reduction efficiency of the important emissions from spark ignition engines.



Infrastructure and pricing issues

Background

The transport fuel marketing has been deregulated since April 1st 2002. This development will have a significant impact on the marketing of these products, in terms of competition in pricing and quality of the transport fuels sold by the oil-marketing companies. The deregulated market allows private and multinational companies to set up marketing network in the country subject to certain entry norms.

The development of infrastructure for production and distribution of the various transport fuels (in the deregulated scenario) that have been covered in the chapter on alternate fuels will be covered in this chapter.

The chapter is divided into the following sections:

- Infrastructure development and principles and factors affecting pricing of conventional fuels.
- Future infrastructure development and pricing of gaseous fuels.

Conventional fuels

The introduction of future emissions regulations is totally dependent on the availability of the fuel of the appropriate quality. The refining industry in India is spread all over the country and has varying degrees of capability in terms of production of fuel quality required for future emissions standards.

The refineries in India can be divided in 3 major categories based on their locations:

1. Coastal Refineries
2. Hinterland refineries
3. Northeastern refineries

The reason for having this categorisation is to point out the constraints that will have to be taken note of for upgrading the refineries in order to produce fuels required for meeting future emission regulations. With India becoming a diesel surplus country since 1999, there are significant exports of diesel from the country. With many refinery expansions planned in the next 2 – 3 years, this situation is not expected to change. In this context it is important to note that in

the current scenario of the country being surplus in diesel, the coastal refineries would have a logistic advantage to export their surplus product. This advantage will be critical for investment decisions to be made and for implementation in quick time.

It is also important to note that for conventional transport fuels, a wide and extensive refining and distribution network exists in the country. The production of fuels meeting future standards depends predominantly on the mandated deadlines announced by the government and as mentioned in the earlier chapter, on competition induced in the sector and incentives that could encourage introduction of changes earlier than the mandated deadlines. The costs of these changes and time required for implementing these changes would vary between different refineries based on their current complexity and the basic infrastructure for production and distribution exists including in far-flung areas.

Production Infrastructure

There is a surplus refining capacity in India with high speed diesel (HSD) and motor spirit (MS) or gasoline comprising the major product exports. Though HSD is showing a flat growth rate currently, gasoline demand in the country is increasing at a significant rate due to the buoyant growth in the two-wheeler and passenger car segment. The refinery configurations vary significantly in the country. In addition to the configuration, the types of crude oils processed are different in different refineries, which brings in differences in pricing between different refineries for the same product at the same marketing location.

The major variation between different refineries in the country is the time frame and cost required for implementing the changes.

Based on the classification of refineries as given in the Mashelkar Committee report (Auto Fuel Policy, 2001), it would be relatively easy for the following refineries to up-grade for production of diesel meeting future fuel quality standards (the constraint is on production of EURO IV diesel quality)

1. IOC Mathura
2. IOC Panipat

These refineries would be critical for supply of diesel and gasoline to Delhi. The other major refineries, which would supply fuels to major cities, which would find it relatively difficult (specifically in case of gasoline) for incorporating changes, are:

1. BPCL Mumbai
2. RPL Jamnagar

3. CPCL Chennai

These refineries are critical for supply of diesel to the cities of Mumbai, Delhi, Chennai and Bangalore. Entry of private oil marketing companies in the near future would induce the much needed competition in the oil-marketing sector and drive oil companies to move towards better quality fuels as it would be possible for the new entrants to import these fuels from cheaper locations.

Transportation Infrastructure

Liquid fuels like diesel and gasoline are not constrained by limited modes of transportation for supply of fuels to different places. However, the mode of transport has a direct bearing on the final retail cost of the transport fuel. The cheapest mode of transportation of petroleum products is by the pipeline mode when compared to transport by rail and road. Table 7.1 provides some of the major pipeline projects that will be the major mode for supply of transport fuels:

Table 7.1 Major HSD and MS pipeline infrastructure in the country

S.No	Origin - Destination	Product (s)	Major Cities catered to
1.	Kandla Bhatinda**	HSD, MS	Jaipur, Delhi
2.	Barauni - Kanpur	HSD, MS	Kanpur, Lucknow
3.	Mathura - Jalandhar	HSD, MS	Delhi, Ludhiana
4.	Visakapatnam - Hyderabad***	HSD, MS	Hyderabad, Vijayawada
5.	Mangalore - Bangalore*	HSD, MS	Bangalore
6.	Mumbai - Pune	HSD, MS	Pune
7.	Baroda - Ahmedabad	HSD, MS	Ahmedabad
8.	Chennai - Trichy - Madurai*	HSD, MS	Trichy, Madurai

Source. (TEDDY, 2001)

* Proposed pipelines

** There is a proposal to convert the Kandla - Bhatinda pipeline to a crude pipeline which could lead to increase in prices of diesel in Northern regions as the mode of transport will change to rail and road from the current pipeline mode of transportation. This proposal is with the Ministry of Petroleum and Natural Gas. If approved this will give enormous opportunities for transport of fuels by road and rail. With rail infrastructure already saturated in terms of capacity, road transportation of these fuels from the Western coast of Gujarat to the Northern regions in large road tankers (more than 25 tons capacity to ensure cost effective transportation cost) will be an attractive mode to ensure lower costs of transportation. Also the development of the road network in the country throws up tremendous potential in the sector of petroleum product transportation in regions which are not connected by product pipelines.

*** This pipeline is completed till Vijayawada and will be extended till Hyderabad by end 2003 and is being built by HPCL.

The policy on use of pipelines as common carriers is not clear with IOC, which is the owner of the majority of the product pipelines (HSD and MS) in the country, not in favour of the common carrier principle but in favour of the owner getting the benefit of first use. This means that many pipeline projects that are proposed might not take off, as the policy on use of pipelines is not clear. With the entry of private oil marketing companies combined with the policy ambiguity on pipeline usage, the potential of movement of diesel by road and rail is significant in the near future^a as marketing network of private oil companies will soon be set up.

With three out of seven metro cities on the coast, transportation infrastructure would be critical only for serving major cities in the hinterland. These cities are Delhi, Bangalore and Ahmedabad which are in the hinterland are all served by pipelines from major terminals / refineries named above.

Pricing issues

The deregulation of the transportation fuels marketing has given the freedom to the marketing companies to competitively price the products. Also offering additional benefits in the fuels by the addition of speciality additives at additional cost is a phenomenon already taking place. The deregulated market ensures in a way the quality of the product in terms of guaranteed quality to the customer to give complete customer satisfaction, which is very important for the image of a branded product.

Subsidy and its impact on diesel and gasoline pricing

The most important issue, which will determine the prices of diesel and gasoline in future, is the phasing out of subsidies on kerosene and LPG used for domestic purposes and will be an aspect that will have to be kept track of.

The Hydrocarbon Vision 2025 report points out that the existing regime of subsidies on LPG and kerosene and tax on gasoline have created significant price distortions among the petroleum products. This has lead to skewed demand patterns and what it calls “dieselisation” of the economy in addition to the mis-direction of subsidies (HC Vision 2025, 1999). It recommended as a first step complete withdrawal of subsidy on LPG and reduction in subsidy on

^a The road transport will be mainly in truck-trailers of higher capacity to reduce the overall cost of transportation, capacities more than 28 KL per truck providing good economics for road transportation of petroleum products. This would be of interest to heavy-commercial vehicle manufacturers.

kerosene in a phased manner. Further it also recommended reduction in the high price of gasoline in line with the reduction in the subsidy level on kerosene.

Currently, the high level of taxation on gasoline is used to meet the subsidy on kerosene and domestic LPG. The previous policy of a fixed price of kerosene and LPG has now changed to a flat rate of subsidy on both kerosene and LPG.

The current subsidies on LPG and Kerosene are given in Table 7.2 below (General Budget 2002-2003, 2002). These subsidies will be phased out, but the time frame for phasing out of these subsidies will depend on the economic policies of the government of the day. As per the original plan of dismantling of APM, the subsidies on kerosene and LPG should have been totally removed by 1st April 2002, which has not happened so far.

Table 7.2 Subsidies on LPG and Kerosene as percentage of cost

Product	Subsidy (% of cost)
LPG	15 %
Kerosene	33 %

The removal of subsidies from LPG and Kerosene will have a major impact on the difference between the prices of diesel and gasoline. The reduction in differential between the prices of gasoline and diesel could impact the demand of vehicles using these fuels. Reduction in the differential will have to consider the aspect of overall fuel efficiency to ensure that there is optimal use of fuel.

Differential between diesel and gasoline – impact on diesel passenger cars

Currently the lower operating cost of the diesel passenger car over the similar power gasoline passenger car allows the diesel passenger cars to be priced at a premium to gasoline passenger cars. This premium could come under stress with the reduction in the differential between the price of diesel and gasoline.

Annex 7.1 give the indicative price build-up of prices of gasoline and diesel based on current taxation structure. The price build-up is also given for the case of ethanol blended gasoline, considering the price of ethanol to be about Rs.14/liter and Rs.18/liter.

Impact of diesel and gasoline surplus in the country

As mentioned earlier, since 1999 the country has transformed from a net importer of diesel and gasoline to a net exporter of diesel and gasoline from the country. Since many countries are fast changing their product specifications to

make them more stringent, product quality will have to be up-graded in order to match the international standards in order to export these products. Also since domestic sales are the most profitable proposition to the oil marketing companies as margins are high, further loss of market share to alternate fuels like CNG, LPG will also be minimised by the oil marketing companies. This situation will also act as a catalyst for up-grading the fuel quality to maintain the share of transport fuel market in the country.

Effect of ethanol blending mandate on gasoline price

As mentioned in the earlier chapter, from 1st January 2003, ethanol blending to the extent of 5 % will be mandatory in gasoline in 9 states and 4 Union Territories (listed in chapter 4). This could have an impact on the price of gasoline and could also lead to price distortions between different places within the same state and across different states. The main reason for this is that the ethanol price and issues related to ethanol supply will not be under the control of the oil-industry. Issues such as cartelisation to increase the ethanol price, as its blending will be mandatory cannot be ruled out at this stage.

The government in the General Budget 2002-2003 announced excise surcharge lesser to the extent of Rs.0.75 /litre on gasohol when compared to gasoline. This incentive, ethanol producers say is not enough to ensure no increase in gasoline price. Therefore, it could become necessary for the government to announce higher level of incentives in order to sustain the ethanol-blending mandate.

The price of gasoline with ethanol price at the depot level at Rs.14.3 /litre and Rs.15.5 /litre does not result in increase in price of gasoline with the current excise exemption of Rs.0.75/litre, but any withdrawal of the incentive or higher ethanol price would result in increase in gasoline price. It is important to note that once ethanol is mandated from a particular date it is not imperative on the government to provide incentive to promote ethanol. This situation could lead to increase in prices of gasoline.

Differential taxation

This is particularly important in the context of same fuels meeting different quality standards available in different places at the same time in addition to ensuring that the better quality fuels are taxed lesser than the fuels of current quality. This will also be important from the aspect of minimising diversion of product from the lower grades to better grades. Though this is a concept that is

widely followed in many countries in the World, the concept has not found favour in the policy initiatives so far in India.

Though no policy direction has been seen in this regard, this will act as an incentive for the refineries and oil marketing companies to up-grade the product quality.

Introduction of VAT by states

The movement from the sales tax structure in different states to a constant Value Added Tax (VAT) in the states could reduce the disparities in prices across states. In this context it is important to note that though many states have agreed to move towards a VAT structure for all products, there is no consensus for introduction of VAT for petroleum products. This introduction of VAT will be an important change that could bring about changes in the prices of petroleum products in future.

Gaseous fuel

The gaseous fuels considered are CNG and LPG. These fuels are vastly different in terms of their pricing and also transportation and distribution constraints. Hence, they are dealt with separately in this section.

CNG

Infrastructure development

The major issue that needs to be understood with respect to the development in the CNG as a transport fuel is the development of a transportation and distribution infrastructure. Transportation of natural gas from the CNG production source will be the most critical issue, which will govern the development of CNG. There is only one cross-country gas pipeline in the country, the 2300 kilometre long H-B-J (Hazira-Bijaipur-Jagdishpur) pipeline that connects Hazira in Gujarat to Jagdishpur in Uttar Pradesh. This pipeline traverses through the following states:

- Gujarat
- Madhya Pradesh
- Rajasthan
- Haryana
- Uttar Pradesh

There are many fertiliser and power plants in the route of the pipeline. It is to be noted that in future based on current demand projections of gas there will be a severe shortfall of gas as a whole.

In addition to this pipeline there is no cross-country gas pipeline in the country for the transportation of gas. There are some regional gas grids basically to move gas from the supply sources directly to some bulk consumers. These grids are not suitable for supplying gas for city gas distribution networks. The lone gas Distribution Company in India is GAIL and it manages all the pipeline network in the country. There are no additional cross-country gas transportation infrastructure planned in the country. The only concrete plans are to expand the capacity of the HBJ pipeline from the current levels of 33.4 MMSCMD to 60 MMSCMD (www.gail.nic.in, Sept 17th 2002). This is still much less than the demand of gas in the northern regions for power and fertiliser sectors as discussed in the following section.

Considering the points made above, it can be noted that other than the places where there is already a gas distribution infrastructure for transport sector, there will be no possibility for development of new markets for gas in the transport sector unless some conscious policy decisions are taken to give transport sector the highest priority in terms of usage.

Gas availability for the transport sector

The most important question that needs to be asked as far as use of CNG in the transport sector on a wider scale in the country is concerned is the availability of natural gas. This issue will be the main driving force for the development of infrastructure for both transportation and distribution.

The demand – supply projections for gas considering only two major gas consumers, power and fertiliser, show significant gap between supply and demand. Table 7.3 provides the demand supply gap projections. (HC Vision 2025, 1999).

Though the value of gas is higher in the power and the fertilizer sector, the Supreme Court has directed that transport sector be given the highest priority in terms of use of gas. This directive was specifically in the case of Delhi. Further to this directive, gas supply to Maruti Udyog at Delhi, Reliance and Essar at Hazira, Gujarat have been curtailed to increase the gas supply to Delhi. This approach may also be followed in other places where there is a demand – supply gap for gas.

Table 7.3 Demand – Supply Gap (MMSCMD)

	2002	2007	2012
Gas Demand Scenario 1	117	166	216
Supply Optimistic	70	64	78
Scenario			
Demand – Supply Gap	47	102	142
Gas Demand Scenario 2	151	231	313
Supply Optimistic	70	64	78
Scenario			
Demand – Supply Gap	81	167	235

Two scenarios presented below gives the demand – supply gap of gas at two levels of imported prices for LNG. Scenario 1 is at \$ 4 / MMBTU and Scenario 2 is at \$ 3/ MMBTU of imported gas. (\$/MMBTU is the standard method of trading in LNG). The scenario 1 represents in a way the actual pricing of imported LNG based on the current agreements that have been reached for LNG supply, hence scenario 1 is the more realistic scenario.

The main demand for natural gas is from power sector followed by the fertiliser sector. The current and projected demand – supply gaps are significant. It shows that unless a conscious policy is followed by the government to give highest priority for use of gas in the transport sector, there will be no additional development in the use of gas in this sector other than in the places where a distribution infrastructure already exists.

Existing distribution infrastructure for CNG

In this context it is important to note that established distribution infrastructure is available only in the following cities and penetration of CNG in other places will have to depend on the establishment of new infrastructure for CNG distribution within the city. The cities are:

1. Mumbai
2. Surat
3. Ankleshwar
4. Baroda
5. Delhi

The Supreme Court in its order dated 5th April 2002 has directed the Ministry of Petroleum and Natural Gas to conduct a feasibility study to ascertain whether CNG can be supplied in 7 places identified by the Court. In these 7 places, the Court points out that the air quality is deteriorating. The 7 places are

Faridabad, Patna, Pune, Jharia, Kanpur, Varanasi and Agra. GAIL is conducting a study to evaluate the demand of gas in sectors other than transport as that would be critical for proper return on investment on gas infrastructure.

Impact of declining share of domestic gas in total gas supply

The Hydrocarbon Vision 2025 points out that after 2001 the domestic gas production would reduce steadily from current levels of 100 % to 25 % by the year 2012. So, it is important to understand that the future strategies on the gas front will have to be based totally on the imported gas. As pointed out earlier among the various options available to import natural, LNG option is the option that will definitely be pursued as some projects are already underway. Also since LNG route will be the source of a significant proportion of the total gas sold in the country, the price of natural gas will also be based on the LNG price.

Pricing of natural gas

The price of natural gas will determine the base price of gas for all consumers. To this will be added other costs like cost of transportation and distribution to arrive at the final price for the consumer in different sectors. The domestic availability of natural gas is continuously declining and it is important to note that future pricing philosophies of gas will have to be based on landed price of imported gas. There are plans to import gas by the following means:

- Import by pipelines from neighbouring countries like Bangladesh, Iran etc
- Import as Liquefied Natural gas from LNG exporting countries.

Among the two options presented above, the second option is the more likely option, as it does not involve any geo-political issues. Terminals will have to be built to regasify the LNG that is imported. The major terminals planned in the country are given below:

- Petronet LNG terminal at Dahej, Gujarat (5 MMTPA)
- Shell LNG terminal at Hazira, Gujarat (2.5 MMTPA)
- Dabhol LNG terminal at Dabhol, Maharashtra (3 MMTPA)
- Petronet LNG terminal at Kochi, Kerala (2.5 MMTPA)
- Ennore LNG terminal at Ennore (near Chennai, Tamilnadu)
- IOC LNG terminal at Kakinada, Andhra Pradesh

Among the various projects mentioned above only the following projects on the West Coast are certain to be completed, as the other projects still do not have definite gas consumers.

- Petronet LNG terminal at Dahej
- Shell LNG terminal at Hazira

This gives about 28 MMSCMD gas in addition to the domestic natural gas whose availability is declining steadily. This again leads to significant difference between the demand and supply of natural gas.

With the major import source of gas being LNG imports, the pricing of natural gas in future will be based on LNG only. To ensure that the LNG terminals proposed are economically viable, the domestic gas price also is proposed to be increased to match the price of gas imported through the LNG route. The indicative price build up for CNG in Mumbai is given in Annex 7.2.

LPG

LPG as pointed out in the section on development of fuels has a major potential in the short term as a substitute for CNG to ensure that the oil-marketing companies do not lose market share. LPG has major advantages with respect to the transportation and distribution when compared to CNG.

Infrastructure

There already exists a marketing infrastructure in the country for marketing of domestic LPG. Additionally only storage facility and dispensers need to be set up in the retail outlets for dispensing auto LPG. With respect to availability of LPG, there already exists infrastructure spread along the west and east coasts for import of LPG. Some of the major terminals where LPG can be imported in cost effective cryogenic (as a liquid in atmospheric pressure conditions and at lower temperatures) form are given below:

1. Visakapatnam (East Coast, Andhra Pradesh)
2. Tuticurin (East Coast, Tamilnadu)
3. Haldia (East Coast, West Bengal)
4. Ratnagiri (West Coast, Maharashtra)
5. Mangalore (West Coast, Karnataka)
6. Kandla (West Coast, Gujarat)
7. Jamnagar (West Coast, Gujarat)

In addition to these facilities which already exist and can be used for import of LPG, there also exist some major pipeline projects which would result in development of auto LPG markets.

The major LPG pipeline, which connects the West Coast to the northern parts of the country, is the Jamnagar – Loni (Uttar Pradesh, near Delhi) pipeline. This pipeline will also have a connection from Kandla to facilitate imports from Kandla if necessary.

In addition to this existing pipeline, the following pipeline projects are already under construction:

- Visakapatnam – Secunderabad pipeline
- Mangalore – Madurai pipeline

The 3 major cities (Visakapatnam, Vijayawada and Secunderabad) in Andhra Pradesh will hence have a pipeline network to support the growth of auto LPG. This region hence has potential to grow as a market for auto LPG. The target for completion of this pipeline project is December 2004 according to GAIL. (www.gail.nic.in, Sept 17th 2002).

It is important to note that irrespective of the pipeline network, auto LPG market can still grow as it can be distributed with as much ease as conventional transportation fuels like diesel and gasoline are dispensed. But as pointed out in the earlier chapter, the growth of LPG in the transport sector will be mainly as a substitute for gasoline in passenger cars and taxis. Mobility, which is an issue concerning the use of CNG in private vehicles, will not be a significant problem as LPG can also be dispensed on highways close to the cities where auto LPG markets are developed.

LPG pricing issues

The major advantage that auto LPG has over gasoline is the price advantage that it has over gasoline because of the lower level of taxes on LPG when compared to gasoline. Also LPG prices are not linked to crude prices unlike the prices of other petroleum products. But there are significant seasonal variations in the price of LPG. Winter prices of LPG are higher than the summer months as the demand for LPG in the winter months is high as LPG is used as heating fuel also. The LPG prices are linked to the tender prices of the largest LPG producer in the Middle East, Saudi Arabia. The major demand of LPG is in the petrochemical sector for the production of olefins like ethylene and propylene. But with Naphtha proving to be a competitive feedstock for production of these olefins, LPG prices have also stabilised and have been flat over the last 2 years except for the seasonal variations in prices. It is also to be noted that Propane and Butane are sold as separate products and customers buy the combination of Propane and Butane as required.

It is also to be noted that import of LPG entails significant ocean freight costs in addition to the cost of transportation of LPG within the country. So though at current level of taxes on LPG, its price is comparable to gasoline, if taxation levels are changed, there would be a significant increase in prices when compared to gasoline.

The indicative price build-up of auto LPG is given in Annexure 7.3.

Conclusions

The following points are critical in the context of development of the fuels in addition to their emissions performance. These would be the guiding principles for increase in penetration of these fuels.

1. With the reduction in the subsidy on LPG and kerosene in phases, the differential between the price of gasoline and diesel could reduce. This will have a significant effect on the choice of fuel specifically where there are options available between diesel and gasoline.
2. The differential taxation between the same fuels meeting different quality norms would also determine the pace with which the better quality fuels are introduced in the market. This apart from competition would play an important role in the process of change of product quality.
4. Unless there is a conscious policy adopted by the government to give use of natural gas in the transportation the highest priority, more than its use in the power and fertiliser sector, the penetration of CNG will be limited to those places where infrastructure for distribution of CNG already exists.
5. The development of natural gas markets for transport will be limited to those places where already distribution infrastructure exists as pointed out earlier.
6. The significant demand – supply gap for the main consumption sectors like power and fertiliser production could result in non-availability of natural gas for the transport sector and would be a major impediment in its growth as a transport fuel in spite of LNG imports.
7. The price of gas in future will be based totally on the LNG prices as the share of domestic gas supply as a total share of gas supply is declining steadily.
8. The tremendous advantage that LPG enjoys over CNG in the aspects of supply, transportation and distribution will help its development in the short-term as pointed above until conventional fuel standards are also improved to match emissions from CNG and LPG powered vehicles.
9. While the prices of CNG, diesel and gasoline depend significantly on the crude prices, LPG prices are not sensitive to crude prices and depend on

other factors like petrochemical product demand and seasonal demand conditions.

10. The logistic advantage (Transportation and Distribution logistics) that auto LPG has over CNG will fuel its development in the country with a transportation and distribution network already existing and further improvements in network already underway.
11. There is expected to be significant development in infrastructure of the auto LPG market in the interim period till quality of conventional fuels like diesel and gasoline are improved till EURO IV levels. LPG will emerge mainly as an alternative to gasoline and will be priced competitively with respect to gasoline.

Annex 7.1

Indicative MS and HSD Price build-up Mumbai with current taxes	Ethanol Rs14.3 /l Ethanol 15.5 Rs/liter			
	Bharat Stage II HSD*	Bharat Stage II MS	Gasohol 5 %	Gasohol 5 %
	Rs/l	Rs/l	Rs/l	Rs/l
CIF Price @ Mumbai	9.039	9.377	9.62	9.68
Price including BCD*	10.8	11.72	12.03	12.10
Price inclusive of customs duty	10.8	11.7	12.0	12.1
Marketing Margin	0.4	0.4	0.4	0.4
State Surcharge Maharashtra	0.32	0.3	0.3	0.3
Price inclusive of Excise duty @ 32 %	13.4	16.0	16.4	16.5
Addl Excise Duty, flat rate	1.0	7.0	6.3	6.3
Subtotal Inc Excise	14.38	23.0	22.6	22.7
Retail pump Operating charges	0.08	0.08	0.08	0.08
Sales tax @ 34 %	4.9	6.2	6.1	6.2
Price including Sales Tax	19.4	29.3	28.8	29.0
Dealers Commission	0.3	0.3	0.3	0.3
Retail Selling Price, Rs/l	19.7	29.6	29.1	29.3
% of tax	65%	67%	68%	67%

Without the excise exemption it could result in increase in prices of gasoline

*There will be a premium for EURO III and EURO IV diesel and gasoline which

Annex 7.2

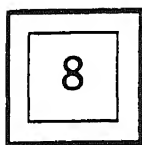
CNG Price Buildup

	CNG import	CNG indigenous
	Rs /kg	Rs /kg
CIF Price @ Mumbai	10.10	8.06
Price including Basic Customs duty @ 5 %	10.61	8.06
Cost of Transportation		
Cost of distribution	4.72	4.72
Price of Gas Sold to OMC	15.33	12.78
Excise Duty	2.45	2.04
Subtotal Inc Excise	17.78	14.82
Sales Tax @ 13 %	2.31	1.93
Surcharge @ 10 % of sales tax	0.23	0.19
Turnover Tax @ 1 % of basic price	0.15	0.13
Price inclusive of State taxes	20.47	17.07
Dealers Margin	1.20	1.20
Retail Price	21.67	18.27

CNG Indigenous is at 115 % of fuel oil parity which gives the complete thermal parity for natural gas
 Cost of pipeline Transportation will be important for interior locations

Annex 7.3

LPG price buildup	Rs/tonne
CIF Price	11000
Ocean Freight	1225
Inland Transportation	3800
Local charges	9750
Excise duty	29899
Total	29899
Cost per kg	29.9
cost per litre	17.0 (density - 0.55- 0.58kg/m3)



Vehicle projections

Background

Road transport is the most dominant form of transport for people and goods in India. There has been a tremendous increase in not only the number of motor vehicles registered but also the road network. In 1998, the number of vehicles in India was over 40 million (Most, 1997). The majority (about 70%) is two-wheelers like, scooters, motorcycles and mopeds. There are approximately 5 million cars, 4.5 million three-wheelers such as auto-rickshaws, 2 million goods vehicles and 0.5 million buses. The percentage of private vehicles (two-wheelers and cars) to the total number of registered vehicles in India has increased from 65% in 1971 to 82% in 1998. Vehicle life is often long; so much of the fleet is over 10 years old. The road network has risen from 0.9 million km in 1971 to 2.47 million km (excluding Jawahar Rozgar Yojna roads) in 1997. Over 80% of passengers and 60% of freight are moved by roads (MoF 2001). Roads cater to all types of traffic. Long distance traffic is served by national highways and state highways, inter- and intra-district traffic by major district roads, feeder traffic connecting rural centres of production to market outlets by other district roads, and local traffic by village roads and urban roads. Augmentation and up gradation of road networks with private sector involvement has been one of the priority areas for the road transport sector as also envisaged in the Ninth Five-year Plan.

Urban transport

The transport sector in urban areas has major problems due to rapid growth in the number of motor vehicles in the cities, so far outpacing the growth in the urban population (Table 8.1). One noticeable feature about the growth of vehicles is the explosion in the number of two-wheelers, cars and auto rickshaws in absence of a good mass public transport system. Further one-third of the total vehicles in the country are registered in the 23 metropolitan cities (each with more than 1 million), and these cities together occupy a little over 8 per cent of the country's population. In the absence of any integrated urban transport policy, there has been a rapid growth in the share of personalized vehicles in the

last two decades. The public transport system has not been able to keep pace with the growing demand in travel, resulting in the use of more personalized modes of transport in the urban areas.

Table 8.1 Growth of population and motor vehicles in metropolitan cities

Major cities	Population			Vehicle population		
	1991	2001 (1991-2001)	Annual growth rate %	1991	1997 (1991-2001)	Annual growth rate %
Mumbai	12,571,720	16,368,084	2.67	629,000	797,000	4.02
Kolkata	10,916,272	13,216,546	1.93	475,000	588,000@	3.62
Delhi	8,375,188	12,791,458	4.33	1,813,000	2,848,000	7.82
Chennai	5,361,468	6,424,624	1.83	544,000	890,000	8.55
Hyderabad	4,280,261	5,533,640	2.60	443,000	769,000	9.63
Bangalore	4,086,548	5,686,844	3.36	577,000	972,000	9.08
Ahmedabad	3,297,655	4,519,278	3.20	374,000	631,000	9.11
Pune	2,485,014	3,755,525	4.22	280,000	468,000	8.94
Surat	1,517,076	2,811,466	6.36	197,000	362,000	10.67
Kanpur	2,111,284	2,690,486	2.45	169,000	247,000@	6.53
Jaipur	1,514,425	2,324,319	4.38	266,000	449,000*	9.12
Lucknow	1,642,134	2,266,933	3.28	216,000	331,000	7.37
Nagpur	1,661,409	2,122,965	2.48	167,000	239,000	6.16
Patna	1,098,572	1,707,429	4.51	180,000	220,000@	3.40
Indore	1,104,065	1,639,044	4.03	214,000	361,000	9.11
Vadodara	1,115,265	1,492,398	2.96	162,000	332,000	12.70
Bhopal	1,063,662	1,454,830	3.18	130,000	242,000	10.91
Coimbatore	1,135,549	1,446,034	2.45	66,000	256,000	25.35
Ludhiana	1,012,062	1,395,053	3.26	202,000	359,000	10.06
Kochi	1,139,543	1,355,406	1.75	29,000	226,000*	40.81
Visakhapatnam	1,051,918	1,329,472	2.37	142,000	207,000	6.48
Varanasi	1,026,467	1,211,749	1.67	112,000	184,000	8.63
Madurai	1,093,702	1,194,665	0.89	38,000	122,000	21.46

Note: @ As on 31st March 1996

* data relates to district

Given that road transport has been growing at a very fast rate, taking an ever-increasing share of passenger and freight traffic, it would be important to study and analyze time-series data and establish causal relationships between growth of motor vehicles and various economic and demographic variables such as per capita income, population, national income, etc. Such empirical relationships would help in making vehicle projections by different categories over the next decade.

In view of this, TERI in its final report would make an attempt to

1. study the available data and compile time series data on growth of all category of vehicles for the period 1981 to 1997 for different states in India.
2. identify the top ten states where the growth of vehicles is higher compare to others.
3. compile time series data on demographic and economic variables that would influence the growth of motor vehicles in the selected states.
4. develop econometric models and establish causal relationships for predicting future growth of vehicles by category in the selected states taking into account growth of the economy and its population.

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